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ORGANIC WASTES AS PLANT GROWTH MEDIA, THEIR USE AND ANALYSIS.

submitted by Shirley A. Landrock-White
for the degree of Ph.D
of the University of Bath
1986

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Summary

Four growth trials were set up to assess the suitability of a number of organic waste materials as alternatives to peat for use as potting media.

Tomatoes, chrysanthemum and nursery stock were grown in physically and/or chemically amended waste materials, which included pine bark, spent mushroom compost, worm-worked animal slurry solids, composted pig slurry solids, leafmould and municipal refuse/sewage sludge compost. Plants were grown successfully in most of the waste materials with appropriate amendment. Growth in municipal refuse/sewage sludge compost was generally poor; boron and heavy metal toxicity being the probable cause.

The waste materials were characterized by chemical and physical analyses, using current M.A.F.F. methods for chemical analysis, and with the development of new techniques for physical analysis. Emphasis was placed on simplicity of methods with advisory use in mind. Growth and yield were correlated with media analysis results using simple and multiple correlation techniques, in an attempt to distinguish the most important medium parameter, and to evaluate the analytical techniques.

Medium salinity (as measured by electrical conductivity) and medium nutrient levels were found to be most closely linked to growth and yield. Virtually no significant correlations were found between physical properties and growth or yield. It was concluded that for advisory purposes the measurement of conductivity and pH followed by nutrient analyses, using the 1:6 v/v moist medium:water extract, could give sufficient information for recommendations for the use of a

variety of waste materials as growth media, provided the physical characteristics of the medium type were known and data from previous growth trials was available. The analytical techniques appeared to be suitable for a wide variety of organic media of different origin.

Short-term growth trials were tested using seedlings and transplants to determine if such a method could be useful in research or advisory work. These tests showed potential for use in research work, but were rejected for advisory purposes as being time consuming and difficult to interpret. Reliance should continue to be placed on nutrient analyses.

CHAPTER 1

Introduction and Literature Review

The Need for New Materials

Many authors have discussed the need to find alternative growth media for horticultural crops, (Pryce (1980a), Conover and Poole (1983), Regulski (1982), Gouin (1982), Gouin (1980) and Chen et al (1983)) most citing the dwindling supplies and increasing price of good horticultural grade peat as the reason. Difficulties in collecting and drying the peat in inclement weather conditions and the increased use of peat for fuel have compounded the potential shortages (130). The demand for growth media is expanding along with the greatly increased output of the container plant industry. The number of container plants produced in England and Wales rose from 50 million in 1979 (118) to nearly 69 million in 1984 (68), with every indication that this trend has continued. Judging by the worldwide interest shown in alternative media these problems are not confined to Britain.

Many alternatives to peat have been investigated and several, including vermiculite, perlite and rockwool, plastic foams and flakes and softwood bark have become well established in commercial use. All these are expensive and most lend themselves best to systems where nutrient levels can be accurately controlled such as the nutrient film technique and rockwool tomato growing systems. Few of these materials would be suitable for the containerized ornamental industry (although some could be used as amendments in mixes).

Alternative media so far studied include black peat, soft and hardwood bark (86), municipal refuse compost, sewage sludge compost, spent mushroom compost, leafmould, corfuna (30) and animal crumb (slurry solids). More obscure materials which have been studied are shredded Melaleuca quinquenervia bark and wood (39,40), corkwaste (150), gasifier residue (the residue from the burning of wood chips and bark)(123), coal cinders (157), lignite (84,7), peanut and almond hulls (21,75), macadamia husks (146), cotton gin trash (107), grape marc and vinasse (the solid residue of the fermentation of grapes)(45), paper waste (71,132), Posidonia oceanica (seagrass) compost (153), volcanic cinder (75,18) and many others.

The availability of many of these wastes is limited to small areas, and their success as growth media has been variable. No single waste material has emerged that is both widely available and suitable in its neat state as a growth medium.

Schmilewski (1984) states that there are in fact huge resources of peat worldwide, but that much is unsuitable for horticultural purposes because of nonuniformity of structure, nutrient content and variable pH. Strongly decomposed peat (black peat) is in abundance, but is structurally unsuitable. Freezing has been found to improve its structure, and Schmilewski predicts that greater use of this type of peat must be made in the future, and allowance must be made for a more diverse range of media.

This leads to problems of standardization of media, both for legal and practical purposes, and in turn to the need for analytical techniques for growth media which are meaningful and can accommodate a diverse range of media.

Presented below is a brief review of the previous

use of the types of waste materials used in this study, followed by a discussion of the analytical techniques in use and the need for standardization.

Municipal Refuse and Sewage Sludge Compost

Waste materials from industry, agriculture and domestic refuse are the most likely candidates for growth media of the future. Many of these materials are rich in plant nutrients, and already present a huge problem of disposal, being buried, incinerated or disposed of in waterways and thus presenting risks of environmental pollution. Strict legislation in the USA in controlling pollution has led to a great interest in the composting of municipal refuse (64), often as a mixture with sewage sludge. Sewage sludge, composted with a bulking agent e.g. wood chips has also been widely researched for use as a growth medium and soil conditioner. It will only be discussed here in the context of municipal refuse/sewage sludge composts, but other uses and problems with the use of sewage sludge and sludge compost can be found in Bunt (1976), Pryce (1980a), Verdonck (1984), Carlile and Sweetland (1984), Búres and Soliva (1984) and Parr and Wilson (1980).

Co-composting of municipal refuse and sewage sludge has been practised in Europe for over 50 years (Stentiford et al 1985 (139)). In Britain composting has never really gained favour following the government working party reports of 1954, 1970 and 1971 on the subject which concluded that composting of municipal wastes could contribute little to the disposal problems of either refuse or sewage sludge (Pryce (1980 a). Composting plants which were built during this period were designed on a materials handling basis, with little thought for the microbial

population or the uses of the end product (Biddlestone & Gray (1973)). Many of these composting systems were expensive to run and highly mechanized (Stentiford (1985) (139)) and this in addition to poor marketing of the product has led to the closure of all large composting plants in Britain, the last (the Wanlip plant, Leicester) closing down in April of 1984.

This situation is in contrast to that experienced in the USA. Composting of sewage sludge, with or without municipal refuse, has been shown to be both environmentally necessary and economical in many states (104,41,127). The major outlets for compost are in land reclamation and ornamental horticulture, and as a low grade fertilizer. Composting has been used as a method of waste disposal in many countries, the compost often being used for horticultural purposes e.g. France (35,37), Belgium (150,156), UK (43,118,141,20), the Netherlands (118), Austria (93), West Germany (3), Switzerland (137), Canada (138,92), and the United States (41,64,14).

Stahlschmidt (1984) found that in "low cost" countries composting of refuse in Dano-type plants (such as that at Leicester) could compete economically with landfilling.

Stentiford et al (1985)(139) have been studying a simplified system of composting sewage sludge and domestic refuse. Their aerated static pile method has proven to be quite successful, producing compost comparable to that produced by most reactor based composting plants (Stentiford (1986)).

Municipal refuse composts often contain high levels of soluble salts (118,3,37,41), particularly potassium, and high levels of heavy metals (also known as PTE (potentially toxic elements). The pH has also been found to be high in many cases (125).

The PTE of concern are boron, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium and zinc, with cadmium being the major element of concern because of its zootoxicity and accumulation in the kidneys with the effect of inhibiting hepatic microsomal metabolism (Sanderson (1980)). Plant and animal pathogens are also present within municipal waste composts, but are generally reduced to safe levels by the composting process (106). However, because of the possibility of accumulation of heavy metals and contamination by human pathogens, the use of refuse compost to grow food to be eaten raw may be inadvisable (43). Davis (1979) stated that the concentrations of Cd in plant parts decreases in the order-

fibrous roots > leaves > seeds = storage organs

suggesting that the growth of leafy food crops on heavy metal contaminated media should be avoided. Several papers on pathogen and heavy metal aspects of municipal refuse and sewage sludge compost use are available, which go into greater detail than that given here e.g. Davis (1979), Coosemans and Van Assche (1984), Pereira Neto et al (1986), Williamson et al (1981) and Sanderson (1980).

Research into the use of municipal refuse/sewage sludge compost as a potting medium indicates that <50% municipal refuse compost mixed with a low salinity diluent such as peat, bark or perlite can be used to grow a variety of plants. Most of the authors grew nurserystock and containerized ornamentals such as chrysanthemum (Sanderson (1980)), Dieffenbachia , Codiaeum and Cordyline (Vleeschauwer et al (1980)). Woody ornamentals were found to grow well in mixes containing 25-50% refuse compost (Sanderson & Martin (1974) and Alt & Höfer (1986)), however, some authors reported evidence of boron toxicity symptoms (60,92)

and reduced growth of nursery stock plants grown in municipal refuse compost containing media when compared to controls (Lumis & Johnson (1982) and Daudin & Michelot (1984)). High pH, high salinity, immaturity of compost and high levels of boron were given as possible causes of poor growth.

Reneaume & Riviere (1981) found that 40% municipal refuse compost could be used with peat as a blocking medium for the successful growth of lettuce and tomato seedlings, and Frey (1981) propagated pea, corn (Zea mays), marigold, cucumber, tomato and pepper in mixes containing 25, 50 and 75% compost with vermiculite, with no apparent differences from the control (100% vermiculite).

Anid et al (1983) grew lettuce, spinach and perennial ryegrass in pot trials and found that inclusion of > 20% municipal refuse compost caused a decline in yield for lettuce and spinach.

Animal Slurry

The recent trend towards more intense animal farming and housing of animals in buildings has led to a problem of disposal of the dung and urine which collect as a semi-solid slurry (Pain (1983)). Application to land, which is widely practised, has caused concern as to the possible pollution of waterways with pathogens and nitrates and the production of offensive odours. This has led to the recent adoption of slurry separating machines which separate the more solid fraction (with 25-30% dry matter) from the liquid. The liquid can then be sprayed onto land and the solids (also known as 'fibre' or 'crumb') provide a more manageable material which will compost readily (Pryce (1980a)).

Slurry composts have high levels of soluble salts

and a pH level which is often > 7. Pathogen levels are reduced to insignificant levels by the composting temperature of 50-70°C which is usually held for several days. Both aerobic composting (Gray & Biddlestone (1975)) and anaerobic digestion (a method of producing energy from waste materials)(Levanon et al (1984) and Hobson and Shaw (1973)) have been used as treatment methods for slurry. Co-composting of animal or poultry manure or slurry with a bulking agent such as straw, bark or sawdust has also been studied (Hon et al (1982), Verdonck et al (1983) and Vleeschauwer et al (1982)). The inclusion of the bulking agent helps to improve the physical properties of the slurry compost by increasing the volume percent air and decreasing the salinity, thus reducing the need for a diluent or leaching at a later date.

Recently, the use of earthworms has been employed to stabilize and fragment animal and poultry wastes (Edwards (1983)). Much work has been done at Rothamsted Experimental Station, Harpenden, Herts, on developing the worm-worked waste technique (Edwards et al (1985)). Initially the technique was used as a means of waste handling and production of earthworm protein for fish and animal feed, but more recently the horticultural value of the worm-worked waste medium has been realised. The most promising slurries for production of work-worked waste for growing media are pig and cattle slurry solids. These slurries are available in quantity, relatively uniform from batch to batch (when taken from the same source), manageable and easily broken down by the worms when applied to the worm beds (wooden sided enclosures with bottom heat (see Edwards et al (1985)) at the optimal rate. The resultant worm-worked slurries are structurally suitable for plant growth media, evenly

fragmented and odourless. The availability of plant nutrients is reported to be greater following worm-working than composting (Edwards (1983)). This may be regarded as a mixed blessing since slurry and slurry composts already contain high soluble salt levels. High levels of zinc and copper are present in pig slurries as these elements are added to the feed of fattening pigs (103) giving possible risk of phytotoxicity, particularly in worm-worked pig slurry.

The worm-working of sewage waste has also been attempted. This will not be discussed in detail here, but some success has been achieved with both the worm-working process and the growth of plants in the worm-worked sludge medium (Neuhauser & Malecki (1984), Daudin & Michelot (1984), Grappelli et al (1985) and Brandjes (1984)).

The economic aspect of worm-working waste is discussed by Fieldson (1984).

Slurry compost and anaerobically digested slurry have been used to grow a variety of horticultural crops. Levanon et al (1984) used digested cattle slurry (Cabutz) as a casing material for mushrooms (Agaricus bisporus) and reported slightly higher yields than with peat casing. Hadar et al (1985) compared anaerobically digested cow manure composted to three stages of maturity and found that the growth of tomatoes on digested slurry composted for 3 months, then cured for 8 weeks, was as good as that on fertilized peat. A number of species were grown by Raviv (1984) on mixtures containing digested cow manure. Philodendron plants grew more rapidly in 1:1 Cabutz:inert material (e.g. perlite, vermiculite) than in 1:1 peat:inert material. No difference was found between growth of Scindapsus and Pelargonium

plants in the Cabutz mixture and the peat control, and the use of Cabutz containing medium for propagation purposes was found to be promising.

Vleeschauwer et al (1982) recommend that not more than 25% chicken manure and up to 50% piggery manure (before composting) should be used in mixtures to produce growth media for ornamentals (because of excessive salinity levels).

Edwards et al (1985) report successful growth of a wide variety of plants in mixes containing 25 and 50% worm-worked wastes with peat, pinebark of loam. They state that "results have frequently been better than with recommended growing media". Plants tested include: Vegetables, bedding, glasshouse and nurserystock plants.

Spent Mushroom Compost

Mushroom compost usually consists of partially composted horse manure and straw with added gypsum to reduce 'greasiness', added N, P and K fertilizers, and a layer of peat and limestone over the top (the casing layer) (Devonald (in press)). Poultry manure or sugar beet pulp may be substituted partially or wholly where horse manure is scarce (Rathier (1982)).

The compost and trays are steam pasteurised following mushroom production as hygiene is very important on mushroom farms, and the compost is then bagged (usually without the casing layer) and sold to the general public as a soil conditioner and organic fertilizer. Much of the compost is sent to tip as the domestic market for organic material is seasonal (spring and autumn) and the spent compost cannot be allowed to collect on the mushroom farm for reasons

of hygiene (Pryce (1980a)).

Spent mushroom compost is thus high in soluble salts, high in pH and subject to shrinkage (further decomposition).

Several authors have reported the need to aerobically compost the fresh spent mushroom compost for 6 weeks to 11 months to reduce levels of ammonium-N and stabilize the structure (Henny (1979), Rathier (1982), Stokes (1976) and Lohr et al (1984b)). Growth trials comparing fresh and aged spent mushroom compost have shown that plants generally grow better in matured compost, but that shrinkage of the compost may still present a problem in long term crops, even after 9 months maturation (Henny (1979)). Lemaire et al (1985) found that most shrinkage occurred within the first 6 months, with 42% of the volume of spent mushroom compost lost by this time. Inclusion of bark or peat in mixes was found to decrease the shrinkage and Henny (1979) recommended the incorporation of at least 30% pine bark to limit shrinkage.

Leaching of spent mushroom compost has been employed as a means of reducing the soluble salt levels (Henny (1979), Lohr et al (1984a) and (1984b)) although Lohr et al (1984a) suggested that "the use of unleached mixes may be preferable because leaching is cumbersome, time consuming, and a potential source of pollution". It has also been suggested (Henny (1979)) that the waterholding capacity of spent mushroom compost may be too high, and volume percent air too low (particularly in large pots) unless an amendment is added to improve aeration. Henny also found a means of reducing the pH to a more acceptable level by the addition of iron sulphate with the fertilizer program.

Henny (1979) grew cuttings of Dieffenbachia

maculata 'Perfection', Pilea cadieri , Peperomia obtusifolia and Epipremnum aureum (pothos) in 100% leached spent mushroom compost and 1:1 leached spent mushroom compost:pine bark. All species grew equally as well in the spent mushroom compost media as in the control and Peperomia grew better than in the control (fertilized 1:1 peat:pine bark).

Lohr et al (1984a) found that transplants of lettuce, tomato, cucumber and marigold (Tagetes patula) grew well in 25% aged (6 weeks aerobic composting) spent mushroom compost with peat (25%) and vermiculite (50%), but plants in 1:1 spent mushroom compost:vermiculite were slightly reduced in quality, whilst Devonald (in press) found that Antirrhinum 'Orange Glow', chinese cabbage 'Pe Tsai', french marigold 'Orange Boy' and Tagetes 'Lemon Jem' grew better in the control (3:1 peat:sand) than in media containing 38-75% spent mushroom compost with peat and sand or bark and sand. Nicotiana 'Domino' was found to grow significantly better in 3:3:2 spent mushroom compost: peat:sand than in the control.

20-30% spent mushroom compost with peat or bark (by volume) are stated by Gartner (1981) to be the mixtures generally used by growers in the USA.

Leafmould

Little interest is present in Britain for producing leafmould in large quantities. The Royal Botanic Gardens at Kew is the only large scale producer of leafmould, utilizing the leaves collected from the parks of central London, and storing them in heaps of up to 5m in height. The production method is very basic; no additives are used to increase the rate of decomposition (accelerators), and no shredding of the

leaves is done at any time. The heaps are turned once only during the summer immediately following collection. Approximately 5000m of leaves are processed in this way annually (Pryce (1980a)).

In the USA the picture is very different. The banning of the burning of leaves in many states and the restricted number of sites which are left which are suitable for landfills has led to an increased interest in the production of leafmould (Derr (1985) and Anon (1984a)). Another reason for this difference in interest is the difference which exists between the nutrient content of British and American leaves. In the USA the short length of the autumn results in the dropped leaves retaining quite high levels of nutrients. British leaves, however, retain few of their nutrients and are not readily composted, unlike the American leaves. In the USA leaves can be composted within a few months (Flower (1983)), whereas at least 2 years are required to break down British leaves. However, economic surveys done by Derr (1985)(USA), Flower (1983)(USA) and Pryce (1980a)(UK) suggest that the production of leafmould is economically feasible on both sides of the Atlantic and that real savings could be made in tipping costs and purchase of growth media. Leafmould could also be sold to local residents as a mulch or soil conditioner. Derr found that even if the leafmould was given away the process could be cost effective as no special machinery or facilities are required.

Because of the intrinsic differences between American and British leaves the leafmoulds also differ. American leafmould is frequently reported to be high in soluble salts (Sawhney (1976)) requiring leaching or dilution with a low soluble salt medium before it can be used for container grown plants.

British leafmould, on the other hand, is very low in nutrients and can be used as a possible substitute for peat (Anon (1979)). Both types tend to be of high pH (>7), although pine needle leafmould is acidic (pH 3.9-5.5)(152).

Relatively little research has been done on the growing of pot plants in leafmould. Traditionally leafmould has had specialized uses such as the use of pine litter for growth of azaleas, and Belgian growers have used leafmould as a container medium for some time (Cull (1982)). Most data on physical and chemical properties of leafmould is to be found in Belgian literature (see Verdonck et al (1982)).

Pryce (1980a) suggests that 100% leafmould (British) may be possible for use as a container medium, but expresses doubts about the use of leafmould in this way because of the possibility of the presence of plant pathogens. Cull (1982) suggests that leafmould may vary between areas depending on tree species. This could make recommendations for its use as a growth medium difficult.

Gouin (1977) composted a mixture of 1 part anaerobically digested sludge to 4 parts leaves. When mixed with sand or topsoil this compost successfully grew containerized Ilex crenata (Japanese holly) and Prunus laurocerasus (Cherry laurel).

Antón et al (1983) mixed leafmould in equal parts with bark and sphagnum peat, and bark and black peat for the growth of Pelargonium zonale and Cineraria hybrida . They found no significant difference between growth in the two leafmould mixes, but significantly better growth in 2:1:1 sphagnum peat:perlite:vermiculite. The difference in growth was attributed to the superior aeration in the peat:perlite:vermiculite mixture.

Bark

Since the beginning of the decade bark has become an accepted growing medium for a large range of plants throughout Europe and America (Verdonck et al (1983)). Both soft and hardwood barks have been used and although fresh softwood bark has proven a possible growth medium, it is generally agreed that composting of the bark prior to use is desirable, and in some cases necessary for the following reasons:-

1. Some barks contain organic substances at phytotoxic levels (tannins, volatile phenolic substances) e.g. Pseudotstuga menziesii (Douglas fir) bark. The levels of these substances can be reduced by composting, although some barks remain phytotoxic even after composting e.g. silver maple (Pryce (1980a)).
2. Bark has a high C:N ratio and substantial quantities of nitrogen and phosphorus are required by microorganisms responsible for its decomposition. Composting with added nitrogen and phosphorus prior to use as a growth medium reduces the competition between the microorganisms and plant and enables the grower to add enough N fertilizers to the bark medium to satisfy the need of both, without increasing salinity above toxic levels (for further details see Bunt (1976), Aaron (1982), Gartner (1981) and Solbraa (1986)).
3. Toxic levels of manganese and possibly chlorine have been found to be present in fresh bark (both soft and hardwood). Solbraa (1986) found up to 120g of manganese per m^3 of spruce bark (Picea abies), most of which was in exchangeable form (Mn++) and available to plants. Oxidation of the manganese to a less available form via composting at pH 6 (or

greater) was suggested as a means of eliminating this problem. Composting the bark with lime, superphosphate and urea was suggested by Bunt (1983) as a means of immobilizing phytotoxic manganese and organic substances.

4. Composting improves the physical structure of bark for use as a growth medium, by decreasing the particle size and increasing the water holding capacity. The water holding capacity of composted bark is still lower than that of peat and more frequent irrigation will therefore be necessary. Solbraa (1986) suggests that 2 parts composted bark:1 part sphagnum peat should give a mixture of sufficient aeration and water capacity for most pot plants.

Many species have been grown successfully in bark mixtures. Pokorny (1982) has reviewed the literature on the uses of bark prior to 1982, and much has been written since. A review here of the many mixes used would be voluminous and not particularly rewarding; bark being used widely as an amendment to increase aeration of denser media as well as the basic component of growth media. The negligible nutrient content and optimal pH (5.0-6.0) (Aaron (1982)) makes bark a very versatile material for inclusion in potting mixes. Bark is also reported to suppress certain soilborne plant pathogens, due it is believed, to the gradual release of phenolic substances (even after composting) and the presence of microbial antagonists (see Hoitink & Kuter (1984) and Hoitink (1980)).

Analysis of Growth Media

The Need for Standardization of Methods

Writers on the subject of growth media frequently refer to the 'ideal medium' quoting specific values for physical and chemical properties. Often, the methods used for the measurement of these properties are not described and thus their significance is beyond interpretation. In addition, to have any meaning in horticultural terms, the parameters must be linked to growth of the plant. Needless to say this process requires much empirical testing of different plant species whilst varying the physical and chemical properties of the medium; a very time consuming process.

Numerous analytical techniques for both physical and chemical properties of growth media have been, and are still being used worldwide. Many of the analytical techniques have been developed from methods originally designed for agricultural crops and field soils (Peterson (1986)). Sometimes the original methods themselves have been used for soilless substrates, giving results which are obviously difficult to interpret. Other researchers have developed new techniques of their own leading to numerous methods which are not easily comparable. Even when different researchers use the same technique they have been known to disagree over the interpretation (Kirven (1986)).

The diversity of analytical techniques has been perpetuated because of allegiances of researchers to their own methods. Kirven (1986) cites economics, accuracy and continuity as reasons for such allegiances. This latter point has prevented many researchers changing their methods, although attempts at correlating results produced by different methods

have been made with the possibility of converting figures from one method to another in mind.

Another reason for the diversity of methods is the apparent confusion existing over the underlying purpose for analysing growth media. Bunt (1986) gives two different objectives for which analysis is undertaken:

1. Advisory purposes
2. Research purposes

and Günther (1983) states legislative reasons. Care should be taken when reading the literature not to confuse these three objectives as the order of priorities will be different for each. For advisory purposes the speed, reproducibility and simplicity of the method are of greatest importance (Bunt (1986); Van Dijk (1980)) along with the ease with which recommendations for amendments can be made, and the accommodation of a wide range of media. For research the order of priorities will depend on the purpose for which the research is undertaken, but accuracy of results and relationship to real growing conditions are likely to be at the top of the list. For legislative purposes the analysis is used to describe the medium in terms of properties which control its quality such as organic matter content, soluble salt content, pH and fertilizer content. The most important property is the bulk density since growth media is sold by volume. Günther (1983) describes the West German standards for growth media DIN 11542 which covers (amongst other properties) percentage organic matter, percentage ash content, bulk density, pore volume, water capacity, air capacity, pH, conductivity and salt content. Several of these measurements are of little interest to the grower e.g. percentage ash content and percentage organic matter, and would be unnecessary analyses for

advisory purposes. Other standards for consumer protection and legislative control are described in Waller & Wilson (1984) (NFU 44-551, French) and Wold (1986) (Norwegian standards).

The accurate measurement of bulk density is crucial whether the analysis is undertaken for legislative, advisory or research reasons since the plant is grown in a certain volume rather than weight of medium. The grower therefore wishes to know how many pots he can fill from a sack of medium and how heavy it will be (for handling purposes). The chemical and physical properties should also be described on a volume basis for all purposes (Günther (1983), Waller & Wilson (1984), Waters et al (1970), Bunt & Adams (1966) and Bunt (1986)). Several attempts have been made to develop a standardized method of measuring a volume of growth media. Boertje (1983) describes the 'Mechanical Compression Routine Method' in which compression with a weight is alternated with matric suction following saturation. Two cylinders are used filled with medium and mounted end to end, the bottom cylinder being used for the measurement of physical properties. During the process of development of this technique four methods were compared with the co-operation of research workers in seven European countries. The findings are fully described in Verdonck et al (1978) and Van Dijk (1980). A review of various methods used by research workers for measuring volumes of medium is presented in the volume measuring section of this thesis.

Further confusion over analysis of growth media has been caused by the use of different units to describe results. Günther (1983) and Kirven (1986) both suggest that an international standard system of units should be adopted for growth media analyses. Günther also states that the following should be the

goals of an acceptable system:

- International conformity of procedures for measurement.
- Statements of procedures for measurement should be put on the analysis report.
- International use of standard reference samples for laboratory testing.
- Standardization of procedures for measurements.

The following pages contain a review of the various methods which have been used for physical and chemical analyses, and the attempts that have been made to standardize the techniques.

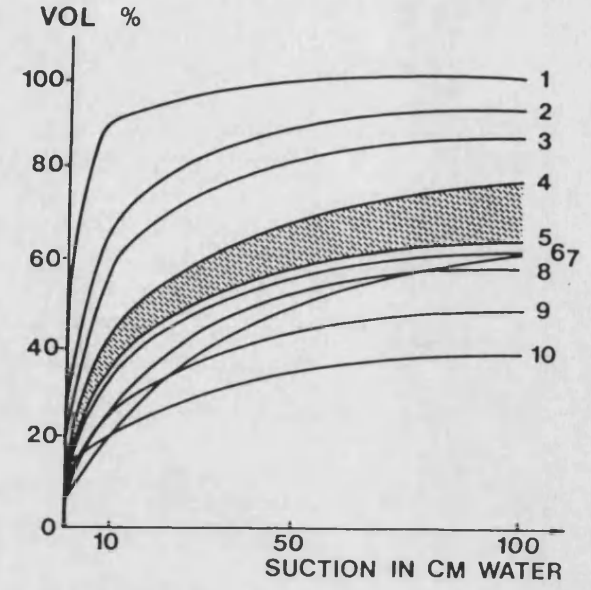
Physical Properties

A number of physical properties of growth media are discussed in the literature and although most authors regard these as being of vital importance to the growth of the plant, little evidence is presented in support of these claims. Paul and Lee (1976) found that aeration, and in particular oxygen diffusion rate (ODR) at container capacity correlated well with growth of chrysanthemum by a quadratic relationship. They stated, however, that the critical value of ODR for maximum growth appeared to vary between media types and plant species and that container depth may also have an influence.

Bunt (1974) investigated the effect of overwatering of tomato seedlings (under winter glasshouse conditions) using peat and sand mixes of various air capacities. When air capacity was reduced below 10% a linear reduction in growth was found for over watered plants, but no reduction in growth occurred with greater than 10% air capacity.

Waller & Wilson (1984) and Verlodt et al (1985) attempted to correlate growth response with physical properties of growth media (e.g. porosity, air capacity, water holding capacity and bulk density), but in neither case were significant correlations found. Waller and Wilson concluded that for air and water capacity 'there would seem to be a wide range of acceptable levels, particularly if the plants are not being subjected to the demands of commercial production schedules or being constantly overwatered'.

The physical properties of the medium will certainly affect the practical aspects of crop production e.g. handling of media and stability of pot plants (bulk density), necessary frequency of watering and fertilizer retention (water holding capacity, total porosity and percolation rate) and amendment proportions (particle size distribution). The most widely used method of characterizing the water relations of media is that described by de Boodt & Verdonck (1972) in which the water, air and solid content (phase distribution) are determined at different water tensions (suctions). Moisture contents at zero tension (saturation), 10cm, tension (regarded as field capacity, or more correctly container capacity; the thickness of the layer of substrate for pot plants being generally 10-15cm), 50cm and 100cm tension (a figure supposed to represent the driest conditions which do not inhibit plant growth, as measured for Ficus sp.) are determined with the use of tension-plate or pressure-plate type apparatus (see Flegmann & George (1975) for details of apparatus). A curve can be fitted through these points as can be seen in fig. 1.1 (from de Boodt & Verdonck (1972)) for different media.



1 STYROMULL
2 POLYURETHANE
3 PERLITE
4-5 IDEAL SUBSTRATE
6 FRESH PINE LEAF MOULD
7 WHITE PEAT
8 PINE LEAF MOULD
9 BLACK PEAT
10 RHINE-SAND

Fig. 1.1 Water Tension Curves for Different Substrates. From de Boodt & Verdonck (1972).

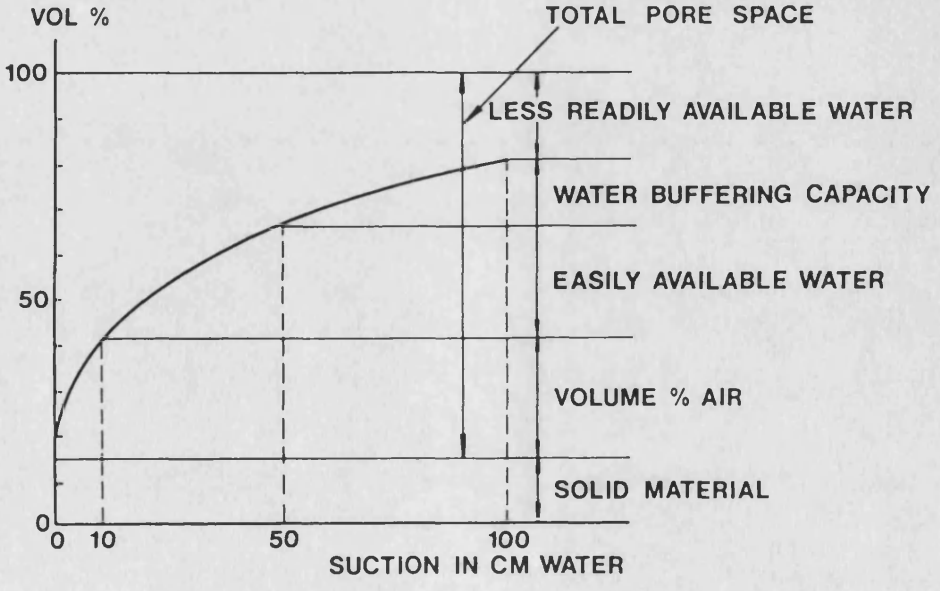


Fig. 1.2 Phase Distribution as Defined Using the Water Tension Curve. From de Boodt & Verdonck (1972).

Fig. 1.2 shows the concept of volume percent air (the difference between zero tension and 10cm tension i.e. between total pore space and container capacity), volume percent easily available water, EAW (that released between 10 and 50cm tension) and volume percent water buffering capacity (WBC) as introduced by de Boodt & Verdonck. They quote 75-90% EAW as optimal for a good substrate. Prasad (1979) utilized this method for characterizing New Zealand peats, wood wastes and Irish peat, on which he introduced the concept of difficultly available water, DAW (water released between pF2 (100cm tension) and pF4.2 (15849cm tension)). DAW was, however, regarded as of limited value in horticulture, tensions below 100cm being of most importance.

Bilderback et al (1982) discusses the limitations which should be considered when utilizing the concepts of de Boodt and Verdonck, but regards their terms as very descriptive and useful in describing and standardizing the water holding characteristics of growth media.

Simpler and/or less time consuming methods for assessing water relations of media (including the determination of container capacity) have been utilized by White & Mastalerz (1966), Beardsell et al (1979), Goh & Maas (1980), Bunt (1984) and Waller & Harrison (1986).

For the method of Beardsell et al total porosity was determined using the particle-density method, and drained water content determined by media containing pots left to stand in water for 48 hours, then drained for 2 hours, followed by oven drying. The volume percent air was then calculated by subtracting the drained water content from the total porosity.

Bunt (1984) describes a container method for

determining total pore space, air capacity and bulk density. In this method 0.5l cans of 10cm depth, with drainage holes, are filled with medium and watered daily with a rose for 8 weeks to simulate cultural conditions. The media, still in the containers, is then saturated overnight on a tension plate apparatus, allowed to drain for 8 hours then weighed, and air capacity calculated.

Goh & Maas (1980) developed a method for the simultaneous determination of air and water capacity of soilless media, using a separate tension funnel for each sample. The medium is contained within double cylinders (diam.=7.6cm, ht.=7.0cm) held together with masking tape, the bottom cylinder having a base made with tightly stretched cheese cloth. A series of immersions in water alternated with gravity drainage are followed by immersion in water for 72 hours, then drainage, which is repeated twice more. Drainage for 4 hours at 30cm tension completes the process of consolidation of the sample. The cylinders are then separated and the bottom one used for analysis. A tight fitting lid with a small hole at the centre is put onto the cylinder and the whole apparatus is submerged completely in water. The lid is pushed down to remove all air before and after a one hour submersion period and the cylinder removed with a finger placed over the hole to prevent drainage. The outside of the cylinder is dried, then the cylinder weighed to give the saturated weight. The drained weight (at container capacity) is also recorded, and weights at 10,20,30,50 and 100cm tension by subtracting the drained weight from the saturated weight.

White & Mastalerz (1966) also used a series of immersions followed by drainage to consolidate and saturate medium samples (in addition to tapping of

the cans on a bench prior to immersion) for the determination of container capacity. 24 hours immersion followed by 24 hours gravitational drainage was used, the cans being weighed after the third drainage, then dried at 105°C. Desorption curves and total porosity were determined using standard methods for soil cores.

Waller & Harrison (1986) developed a method which could be completed within one hour and compared well with the desorption curve method of De Boodt and the container method of Bunt (1984). Four aliquots of 400ml of a wetting solution are added to 1l of medium (measured by the FIBSPAN method) with a rose, each aliquot being allowed to drain below the surface of the medium before the next is added. The beakers (10cm diam., 1l vol. with 6x8mm drainage holes) are left to drain for 30 minutes, then weighed. The drained volume is determined using 5x6mm diam. calibrated rods which rest on the surface of the medium. Particle density is taken as 1.5 for peat or determined by displacement of paraffin. These measurements, with weight of the dry matter, give sufficient information to calculate the air-filled porosity (volume percent air).

Particle size analysis is easily undertaken by the use of various sieve sizes. Waller & Wilson (1984) state that although the particle size distribution influences air and water volumes these properties can be more reliably measured by direct means. Handreck (1983) and Jinks (pers. com.) found that only those particles of less than 0.5mm in diameter had a significant influence over the water release and air filled porosity. Handreck found that Pinus radiata bark particles in the range 0.1 to 0.25mm decreased air-filled porosity and increased water release to a

greater extent than did either those in the 0.25-0.5mm range or <0.1mm range.

Jinks found that a strong correlation existed between aeration, water capacity and the proportion of sphagnum peat particles <0.5mm regardless of the proportion of particles making up the rest of the mix. Table 1.1 (from Verdonck & Penninck (1986)) illustrates the findings of Handreck (1983) and Jinks (pers. com.) well.

The measurement of the proportion of particles of <0.5mm diameter could thus give an indication of the water relations of a medium, and also be of use in the prediction of physical properties when amendments are used.

Spomer (1974) introduced the concept of the "Threshold Proportion" for amendments. This is the proportion of amendment at which the total porosity is a minimum, and goes some way towards explaining the interaction between particles of different sizes and the optimizing of medium mixtures (see fig. 1.3). Equations are given which predict mixture total and aeration porosities from component bulk volumes and porosities.

Other equations have been reported which correlate certain physical properties to other physical properties. These have been produced in attempts to reduce the number of different determinations which are necessary in order to physically characterize a medium.

Prasad (1979) found that an inverse relationship existed between bulk density and air capacity and between bulk density and total porosity. Whilst other researchers who have attemped to correlate these properties would agree that total porosity was significantly and negatively correlated to bulk density, no other author has reported a significant

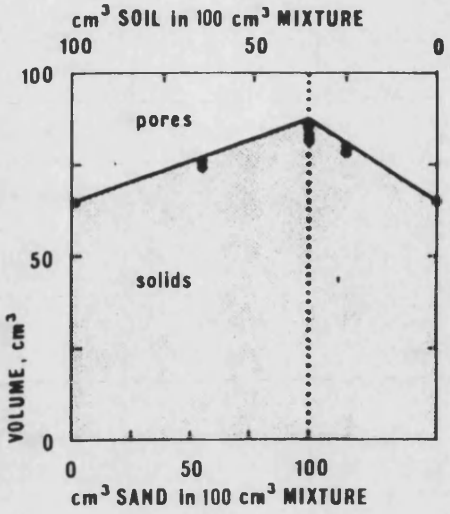


Fig. 1. Effect of increasing volume proportions of a monodisperse[5] river sand amendment (100% passed ASTM sieve #18 and 0% passed #30) on total pore volume of compacted soil (powdered silty clay loam). Mixture bulk volume is 100 cm^3. The solid line is the theoretical porosity (equations A, B, C) and the dashed line is the threshold proportion. All data from 5 replications are shown. Vp = pore volume, V_S = solid volume.

Fig. 1.3 The Treshold Proportion Concept. From Spomer (1974b).

Physical parameters of peat with different particle size.

Size of particles	Bulk density in g/cm^3	Total pore spare	Volume % water at a tension of			Volume % air	Volume % easily available water
			10 cm	50 cm	100 cm		
< 2 mm	0.170	88.3	19.7	16.9	16.3	68.6	2.8
1-2 mm	0.205	85.9	21.5	17.4	16.1	64.4	4.1
0.5-1 mm	0.238	83.6	27.1	16.9	15.1	56.5	10.2
< 0.5 mm	0.281	80.6	63.6	17.6	13.9	17.0	46.0
total material	0.212	85.4	78.0	42.2	35.5	7.4	35.8

Table 1.1 The Effect of Particle Size on Phase Distribution. NB the Influence of Particles <0.5mm on Volume % Air and Volume % E.A.W. From Verdonck & Penninck (1986).

relationship between bulk density and air capacity, Beardsell et al (1979), stating that air and water holding capacity cannot be related to bulk density as these properties depend on the ratio of macro- to micropores, these varying considerably between media. Prasad (1979) used mainly peat media for his determinations, which probably had similar phase distributions, making the existence of a correlation between bulk density and air capacity possible.

The equations produced relating total porosity to bulk density are remarkably similar despite the use of a wide variety of materials in the determinations. Beardsell et al (1979) used mixtures containing sand, volcanic scoria, pine bark, poppy straw waste and sawdust. Hanan et al (1981) used sphagnum peat, pine bark, almond hulls, sheep manure, clay and sand, and Bunt (1984) used peat mixed with perlite, vermiculite, calcined clay, sand or grit.
The equations are, respectively:-
(TP=total porosity %, BD=bulk density Kg/l)

$$TP = 94.1 - (32.8 \pm 1.6)BD \qquad r = -0.96$$

$$TP = 98 - 36.2BD \qquad r = -0.99$$

$$TP = 98.396 \pm 0.264 - (36.554 \pm 0.364)BD \qquad r = -0.998$$

Chemical and Physico-chemical Properties

Greater success has been achieved in the attempt to standardize the methods for determining the chemical properties of soilless growth media than for the physical properties. A symposium was held in October of 1983 entitled "Interpretation of Extraction and Nutrient Determination Procedures for Organic Potting

Substrates" at which it was proposed that the Saturated Medium Extract (SME) procedure for nutrient analysis should be adopted (Bilderback (1986)). However, Bilderback concluded that the adoption of a standard procedure seemed unlikely at that time.

Kirven (1986) compared nutrient analysis results from different research workers using different (and in some cases the same) extraction techniques, and concluded that the results were dependent on the extraction procedure, and that they may differ even between researchers using the same techniques. Kirven states that because of the high value of horticultural crops, the adoption of a standard analytical procedure, or the production of a procedure for comparing methods is imperative.

Bunt (1986) describes and discusses the different extraction procedures in common use for the determination of water soluble and exchangeable nutrients:

Saturated media extracts - for research
Displaced soil solutions - for research
Suspension methods - for speed and convenience.

Suspensions

For these methods a fixed volume or weight of fresh or dried medium is suspended in a volume of extractant. Most researchers have rejected the use of a extraction technique based on a weight of medium as being meaningless in practical terms, preferring a volume basis. Recently the preferred extractant for soilless media has been deionized water with the ratios 1:1.5 (Sonneveld et al (1974); Prasad et al (1981a)), 1:2 (Waters et al (1970); Wilson (1986)),

and 1:6 (Johnson (1980)) v/v fresh medium: water being used.

A number of different extractants have been used, some of which are supposed to estimate the exchangeable macronutrient levels as well as water soluble levels. Markus (1986) compared different weak acid extractants; Spurway extract (0.018N HOAc), boric acid and double acid (0.05N HCl in 0.025N H_2SO_4), and concluded that all were effective extractants of mineral nutrients. Linear correlations were found to exist between the acid extractant methods and between acid and non-acid extractants. Greater quantities of nutrients were removed by acid than by non-acid extractants, and it was found that air dried medium released lower macronutrient levels than moist medium. Drying of medium is thought to result in a disturbance in the ionic equilibrium of the medium (Markus (1986)) with a reduction in the extractability of NO_3-N, P, K, Ca and Mg and increased release of NH_4-N (Bunt (1986)). Difficulty in rewetting may also occur following drying. Wilson (1986) compared saturated calcium sulphate, 0.5M acetic acid and distilled water for the extraction of nitrogen, phosphorus and potassium. He concluded that to remove exchangeable ammonium-nitrogen and potassium, calcium sulphate or acetic acid should be used as the extractant, and that a ratio of 1:2 v/v fresh medium:extractant was preferable. Table 1.2 shows the effect of increasing the ratio of extractant:medium on pH, conductivity and extracted nutrient levels.

Prasad et al (1981a-e), in a series of papers, compared the Dutch 1:1.5 water extract method, for extraction of phosphorus and potassium, with the Olsen's extract for phosphorus (0.5M $NaHCO_3$, pH8.5, 1:20 sample:extract) and ammonium acetate extraction

Effect of sample extractant ratio on analyses

Extraction ratio	Conductivity	pH	ppm in fresh			
			NO_3"N"	NH_4"N"	P_2O_5	K_2O
1:1.5	830	5.66	110	2	189	443
1:2	700	5.72	117	3	192	490
1:3	490	5.82	135	4	219	551
1:5	338	5.96	155	5	247	620

Table 1.2 The Effect of Increasing the Ratio of Extractant:Medium on pH, Conductivity and Extractable Nutrient Levels. From Wilson (1986).

Simple regressions of Levington analysis on the Dutch analysis

Determination	Constant	Coefficient	r
pH	2.96	0.592	0.764
P	13.5	0.849	0.947
K	52.0	1.00	0.989
Mg	5.7	0.869	0.918
Conductivity	249	0.916	0.963
NO_3-N	42.2	0.659	0.551

Table 1.3 Equations Relating the 1:6 Water:Medium Extract (Levington Method) to the 1:1.5 Extract (Dutch Method). From Johnson (1980).

for potassium. They also evaluated the 1:1.5 extract for the determination of nitrogen, phosphorus and potassium by relating their extraction results to plant uptake. A linear relationship was found between the 1:1.5 and Olsen's extract methods for phosphorus, but the gradient of the regression line was found to vary with the quantity of P present i.e. at higher rates of P the slope was less steep than with lower rates. A good linear relationship was found between the two potassium extractant methods which did not vary with the quantity of K present. Quadratic relationships were found between extracted nutrients and plant uptake. Whilst this relationship was very good for all media for potassium, the relationships for N and P deteriorated when more than one type of substrate was included. Prasad et al concluded that the uptake of nutrient per unit of substrate test value was not constant for all materials and that for phosphorus no general equation would be available for converting one extraction method to another for all substrates.

Johnson (1980) compared the 1:1.5 extract to the Levington 1:6 v/v water:fresh medium method. He concluded that both methods correlated well (except for NO3-N) but the 1:1.5 method was unacceptable for routine rapid analysis as it required the adjustment of the sample water content to pF 1.5 before analysis. The use of a wider ratio (i.e.1:6) of medium:extractant overcame the necessity to do this. Table 1.3 gives the equations found for conversion of results from the 1:6 (Levington) method to the 1:1.5 method (for peat, bark and peat + sand substrates).

Gabriëls et al (1985) describe a computer aided soil testing method which can predict crop response from medium nutrient contents, pH, conductivity,

nature of the substrate, growth stage and method of cultivation. A letter of recommedation for the grower is the end result. for the determination of P, K, Ca, Mg, Na, SO4, Fe, trace elements and heavy metals a 1: 5 v/v fresh medium:ammonium acetate extraction is used and for NO3-N, NH4-N, Cl, F, HCO3, B and Br bidistilled water is used as the extracting solution PH and conductivity are determined on a 1:2.5 medium: bidistilled water extract. This type of approach could be very useful if an internationally adopted standard method of analysis were used, and experimental data pooled.

Saturated Media Extracts and Displaced Soil Solutions

As stated in the introductory paragraph the symposium of October 1983 concluded that the SME procedure should be adopted for nutrient analysis of soilless media. In this method 500cm^3 of fresh medium is mixed with distilled water until just saturated. After equilibrium for 1.5 hours the pH is measured and the solution extracted with a vacuum filter for further analysis. Good correlations were found between this and the Spurway extraction technique (Warncke(1986)), and the SME procedure was considered quicker to do and more realistic since the moisture holding capacity of the medium is taken into account. Decreasing variability between analyses was also thought to exist with decreasing medium:extractant ratio. One major problem found with this procedure was the definition of the exact point of saturation. In a study including seven laboratories using the same media (Warncke (1986)), variability in results between laboratories was found

to be quite high. The inability to mix a variety of growth media consistently to saturation point was thought to be the cause. Warncke concluded that greater experience with this method would help the situation. This method would not, therefore be acceptable for routine advisory purposes where a simple, easily reproducible, method is required, but it is considered by Bunt (1986), Waters et al (1970) and Warncke (1986) as the best method for research purposes after the displaced soil solution method. In the latter method a constant head of liquid (immiscible with the soil solution) is used to displace the soil solution from a column of medium (Bunt (1986)). A variation of this method is the 'Press Extract' in which the substrate solution is removed with the use of a hydraulic press. Sonneveld et al (1974) found that a good linear relationship existed between the 1:1.5 extract and the 'Press Extract' for nutrients and conductivity.

Hydrogen Ion Concentration (pH)

The pH of the medium is of major importance as it affects the availability and therefore the balance of nutrients, particularly that of minor nutrients.

Flegmann & George (1975) explain that two types of information can be obtained from pH measurements as follows: "A single pH measurement on a soil suspension gives the concentration (or, strictly, the activity) of the hydrogen ions in a solution in equilibrium with the soil. A measurement of this kind gives an indication of the momentary acidity of the soil. Two or more pH measurements are necessary for determining the titratable soil acidity which is the amount of base required to bring the soil to a predetermined pH value". The latter could be

described as effectively the buffering capacity of the soil and is used in determining the lime requirement.

The pH is generally measured on the extract used for nutrient analysis with the use of a glass electrode connected to a pH meter, or with a tougher Spear Electrode for saturated samples.

The soluble salt concentration of the extractant used will affect the pH found, since the higher the concentration of ions in the extractant, the lower the pH of the medium (as measured) will be. Flegmann & George (1975) attribute this effect to the replacement of exchangeable hydrogen and aluminium ions on the soil matrix by cations from the extractant. The magnitude of this effect will depend on the structure and cation exchange capacity of the medium.

A commonly used extractant for the measurement of pH of soils is 10^{-2} M calcium chloride with a soil:extractant ratio of 1:2.5. The ratio of soil:extractant and concentration and type of extractant used should always be reported with pH results. The effect of increasing the ratio of extractant:medium on pH is shown in table 1.2. Increased extractant:medium ratio leads to dilution of the salts present (although additional salts may come into solution) and an increase in the pH (known as the soil-water ratio effect). The SME and displaced soil solution extracts, therefore, represent the pH experienced by the plant better than suspensions of greater extractant:medium ratio. Alternatively a weak exectrolyte extractant can be used to counteract the soil-water ratio effect (Bunt (1976)).

The effects of medium pH on plant growth are complicated. Plant species vary in their optimal soil

pH levels for growth. Higher concentrations of hydrogen ions than that found at pH 4.5 can interfere with root function and damage roots, but the major effect of pH is that of controlling the solubility of salts. Toxicities and deficiencies (particularly of micronutrients) can occur at sub-optimal pH levels. The optimal pH for many plants grown in field soils is in the region of 6.5 (Flegmann & George (1975)), and 5.0-5.5 for organic media (Bunt (1976)).

Salinity

Plants vary widely in their ability to tolerate soluble salts (see Appendix 2 for examples). Maas & Hoffman (1977) give a thorough account of crop salt tolerance, the factors influencing it and include a table of threshold salinity levels (above which yield begins to decline) and the rate of yield decrease with increasing salinity for a number of crops. Unfortunately floricultural crops are not included in this table. Maas & Hoffman found that yield was not significantly decreased until a certain threshold salinity was reached, above which yield declined approximately linearly.

Bernstein (1964) defines salinity as "the prescence of excessive concentrations of soluble salts", the lower limit for salinity being that at which a significant decrease in plant growth, yield or quality of the crop occurs, and Maas & Hoffman (1977) point out that "salt tolerance is a relative value based upon cultural conditions under which the crop was grown...Absolute tolerances that reflect predictable inherent physiological responses by plants cannot be determined because many interactions among plant, soil, water and environmental factors influence the plants ability to tolerate salt". They

go on to describe the various factors which influence salt tolerance, summarized as follows:-

Plant Factors

1. Stage of growth - Salinity tolerance may vary from one growth stage to another.

2. Varieties and rootstocks - Varietal differences for salt tolerance are not common, although some have been reported for Gramineae and Leguminosae. Rootstock differences are of importance in the salt tolerance of fruit trees and vine crops.

Soil Factors

Apparent salt tolerance may vary with soil fertility. Bernstein (1964) goes into some detail on the effects of salinity on soil nutrient balance for corn and beans, suggesting that high levels of calcium can influence nutrient balance in the plant either beneficially (corn, tomato) or injuriously (bean).

Soil, Water and Aeration

The drier the soil, the more concentrated the soil solution will be, and the higher the osmotic potential. Water uptake by plants is limited by both the soil matric potential and the soil solution osmotic potential, thus the higher the osmotic potential the greater the irrigation requirement. This may lead to overwatering and lack of aeration in the medium; possibly adding oxygen deficiency to the salinity effects.

Environmental Factors

When transpiration rates are high i.e. under conditions of high temperature and low humidity, plants are generally less tolerant of saline

conditions because it limits their water uptake (e.g. summer crops are likely to be less salt tolerant than winter ones (Bunt (1976))).

Salinity Effects on Plants

Bernstein (1964) divided salinity effects on plants into three catagories:-

1. Osmotic effects
2. Specific ion effects (nutritional)
3. Toxic ion effects

1. The osmotic effect of salinity in decreasing water uptake is considered the most important factor in causing injury to plants. Flegmann & George (1975) state that experimental evidence is present which shows that the effect on water uptake of solutes added to the soil solution does not depend on the nature of the solutes, but on their concentration. Bernstein (1964) also suggested that this was the case, stating that with beans and corn "both crops exhibited rather wide latitude with regard to their tolerance to mixed-salts solutions of different proportions". The most common injury caused by salinity is the stunting of the top growth of plants, with possible thickening of leaves and increased leaf :stem ratio.

2. Specific Ion Effects Bernstein (1964) found that in a few genera specific ion effects of a nutritional nature depressed growth and yield more strongly than the osmotic effect of the medium e.g. tomatoes often exhibit blossom end rot caused by calcium deficiency under saline conditions, particularly when high concentrations of sodium are present.*

3. Toxic Ion Effects Occasionally specific toxicities can occur under saline conditions e.g.

* Other causes of Ca deficiency exist under saline conditions e.g. high NH_4^+ limits Ca uptake.

leaf scorch symptoms of chloride and sodium toxicity in fruit crops, and boron and manganese toxicities.

Electrical Conductivity (EC)

Waller & Wilson (1984) regard the measurement of electrical conductivity as giving a meaningful estimate of the soluble salt content of a growing medium, but that it may be a misleading measure of fertilizer content; not all ions being known to be useful plant nutrients. The EC does not, however, take into account non-electrolytes (e.g. urea) which also contribute to the osmotic stress which the plant experiences.

Bernstein also considers that electrical conductivity can be used to assess the salinity of media for most crops and conditions, as electrical conductivity is highly correlated with osmotic potential by the equation:-

Osmotic potential (ψ_o) = -0.36EC (Maas & Hoffman (1977)).

Bunt (1976) describes the different methods available for the measurement of salinity, the most commonly used being the measurement of electrical conductivity on a saturated paste or medium suspension. Distilled water may be used as the extractant, but for suspensions, saturated calcium sulphate can be used to eliminate the effect on the conductivity reading of extra solublization of this salt in the extractant (over and above that soluble at container capacity). The medium solution is frequently saturated in calcium sulphate, some remaining insoluble (particularly in soil based media). This salt contributes little to the osmotic potential of the medium solution.

Indicator Crops and Seedling Tests

Short-term growth trials and germination tests have been used by a number of authors to assess the suitability of media for plant growth, to determine the maturity of compost, and as indicators of heavy metal contamination of soils.

Sphon (1969) described a cress (Lepidium sativum) test which was found useful in indicating the maturity of town refuse compost. Hadavizadeh (1982) used a similar test with mustard and cress plants to confirm predictions based on compost analyses for composted pig slurry solids and paper waste. 1g of mustard and 1g of cress seed were sown in two halves of a half size seed tray (25x12cm) and allowed to grow for 7 days. Plants were cut at medium level and fresh weight recorded. Hadavizadeh (1982) also grew tomato transplants for twenty days, these also confirming predictions based on medium analyses.

Zucconi et al (1981) developed a rapid germination test utilizing cress seed, in which seed are placed in 5cm petridishes lined with filter paper containing 1ml of a press extract of the compost under test. It was concluded that 24 hours at 27°C in the dark, and 15 replicates of 6-8 seeds were sufficient to give an accurate indication of the maturity of the compost. A germination index of germination x root growth (both expressed as a percentage of the control) was used as the parameter of measurement.

Stentiford & Pereira Neto (1985) developed the technique of Zucconi et al (1981) for their own purpose to assess municipal refuse/sewage sludge compost. Seed trays filled with compost were used and the Emergence Time Ratio (ETR) developed intead of the germination index of Zucconi et al. For this

method sweet pea seeds were used; the ETR equalling the mean time for a seedling to appear from the test compost divided by the mean time for a seedling to appear from the control compost. A problem found with this method was that poor environmental conditions caused the mean time for a seedling to appear from the control compost to be extended, and the ETR reduced. Standard environmental conditions were thought to be necessary to minimize emergence time in the control.

Frey (1981) attempted to assess the quality of municipal refuse compost by germination of a variety of plant species; pea, sweet corn, marigold (Tagetes sp. 'Fantastic'), cucumber, tomato and pepper (Capsicum cerasiformae 'Large Cherry'). No predictable significant trend was found when comparing the germination of the species; differences being attributed to differences in salt tolerance between the species.

Waller and Wilson (1984) and Davis (1979) regard growth tests as being desirable for assessing the quality of a growth medium. Waller & Wilson (1984) consider growth trials as a necessary part of the process leading to product registration and approval, stating that "The overall performance of a growing medium is a complex interaction of many factors and its quality can only be assessed by growing tests." In this case plants were grown to anthesis.

Davis (1979) considered seedling trials as a method of indicating the contamination level of soils. It was suggested that tissue analysis of indicator crops could provide useful information on the level of heavy metal contamination and that standardized tests should be used, such as the use of barley harvested at tha 5 leaf stage. Davis concluded that although standardized plant tests take longer than

soil analysis, they are easy to set up and give more direct results. Blunt (pers. com.), however, regards the use of indicator crops to assess soil contamination and nutrient levels as not really feasible, since it is not possible to isolate effects of individual elements from possible nutrient imbalances. Blunt considers that chemical analysis of soil gives the most useful and easily interpreted test.

Introduction

The preceding pages give an account of some organic waste materials which could possibly be used as alternatives to peat as plant growth media. The following experiments were designed to test these materials for suitability as growth media, and to give an indication of any necessary amendments. However, the primary aim of this project was to outline the chaotic situation which exists with respect to medium analysis and to provide information as to which analytical techniques best indicate the suitability of organic wastes as potential media. Since the work was funded by M.A.F.F emphasis was placed on the simplicity of techniques (with advisory use in mind) and existing A.D.A.S. analytical methods were used. Simple and multiple correlation techniques were used in an attempt to link plant growth and yield to medium factors, and the use of short term seedling and transplant trials for rapid assessment of growth media was investigated. Physical breakdown of the waste materials over time (i.e. shrinkage in the pot) was measured as these media are most likely to be of use in the containerized ornamentals industry.

CHAPTER 2

Materials and Methods

The following were included as growth media in this study:-

NAME	SOURCE	NATURE
Cambark Fine	Camland Products Ltd., Cambridge.	Finely screened pine bark designed for seed, potting and blocking media, top-dressing for lawns, sports fields and golf tees.
Leafmould	Royal Botanic Gardens, Kew, Richmond, Surrey.	Leaves, collected from London parks comprising mainly London Plane (Platanus X hispanicus) composted in heaps over 4m in height and turned occasionally during a 2 year period.
Beech Leafmould *	Bath University.	Approx. 1600 litres of beech leaves collected from the Bath area and placed in a brick surr-ounded compound to a depth of 1m. The leaves were turned twice during a 2 year period.

Spent Mushroom Compost	Byfield Mushrooms Bath.	Composted horse manure used once for mushroom production and therefore containing mushroom mycelium and stipes.*
Worm-Worked Pig Slurry and Worm-Worked Cow (Cattle) Slurry.	Dr K.E.Fletcher Dept. Entomology Rothamsted Expt. Station, Harpenden, Herts.	Animal slurry solids fed to worms in brick surrounded, drained and heated beds. The worms (Eisenia foetida), convert the organic matter into casts high in available plant nutrients and stabilized in structure.
Pig Slurry Compost	G.F. Shattock 5, Orchard Close, Long Lane, Tilehurst, Reading, Berks RG3 6YS.	Separated pig slurry solids, composted in a static pile with positive pressure aeration for 35 days. The resultant compost was left to dry out for a further 10 days.
Lescost @	Wanlip Composting Plant, Leicester.	A compost derived from a mixture of dried digested sludge and refuse, composted in Dano Stabilizers for 4 days, and in windrows for 12 weeks. Rags and metals are removed prior to composting and screening down to 3/8"

* Majority of casing removed.

Doncaster Compost	E.I.Stentiford Dept. Civil Engineering, Leeds University.	Unsorted domestic refuse from Doncaster, S. Yorkshire, was shredded and mixed with sewage sludge (4-5% solids). This was composted in a static pile with positive pressure pressure aeration for 3-4 weeks. The pile was then removed from the aeration pad and stored in a heap to mature for 4 months. Sieving through a 5mm mesh produced a compost suitable for a low grade fertilizer and soil conditioner. (141)
Levington Potting Compost	Fisons PLC Ipswich.	Sphagnum peat based proprietory potting medium.
Levington Universal Compost	Fisons PLC Ipswich.	Peat and sand proprietory potting medium.
Sedge peat		A finely divided dark sedge peat with no additives.
Sphagnum peat		Horticultural grade Irish sphagnum peat.

@ The Wanlip plant closed down in April of 1984.

* This medium was not used for growth trials, but shows the ease with which leafmould can be made, and its characteristics after 2 years.

Sampling

All growth media were thoroughly mixed before sampling. After turning each stack of medium twice 12 cores were taken using a section of square drainpipe 22cm long, and 6x6cm. This sample was taken to the laboratory where it was again mixed well and any large lumps (those larger than the average) were broken down or removed. Representative subsamples were taken from the original sample for chemical and physical analyses. The remainder of the original samples were then stored with the rest of the media outside under polythene sheets to ensure they received the same conditions as the main batch of medium.

Analytical Techniques

Chemical and physical characterization of the growth media was the first step in this study. Chemical analysis proved relatively easy, whilst the physical aspects were more difficult and time consuming to determine. Both total and available nutrient levels were determined, the media being treated in the same way as plant material for total nutrients and as peat compost for available nutrients. The ADAS method of dry combustion (Method 3 RB427) (9) was adapted as follows for the determination of total nutrients:-

Growth media were dried in kilner jars for 16 hours at 102°C (± 2°C) and cooled with the lids firmly on. 1g of sample, measured to 0.002g accuracy and ground in a Glen Creston 14.480 micro hammer mill to pass through a 1mm sieve, was measured into a tall 125ml beaker and transferred to a preheated muffle furnace at 450°C. The door was shut for one minute then left open for 5 minutes until ignition of the sample was complete. It was then left closed for 1.5 hours. The samples were then removed from the oven and allowed to cool, each beaker covered by a watch glass, then moistened with a little deionized water and dried (uncovered) on a bench heater. The beakers were then returned to the furnace for a further half hour, removed, cooled, moistened, dried and returned for a further half hour, giving 2.5 hours in the furnace altogether. No increase in nutrient content was found with further ashing although some residue, presumed to be silica, remained in each case. The cooled ash was dissolved in 5ml of 6M hydrochloric acid and evaporated to dryness. 2ml of 36% w/w hydrochloric acid was added, the beakers covered with a watch glass and the solution boiled gently for two minutes. This was done over a low heat as the silica residue causes spitting. 5ml of deionized water was then added and the mixture boiled again. It was allowed to cool, diluted to 25ml and filtered twice, once through Watman no.541 filter paper and once through a 0.22µm micropore filter, rejecting the first few mls of extract in each case. The extract was used for the determination of the following total nutrients:-

Potassium
Phosphorus
Calcium
Magnesium
Iron
Manganese
Copper
Zinc
Nickel
Lead
Cadmium
Aluminium
Sodium

Available nutrients were determined from a 1:6 v/v medium:water extract (10) which was shaken for one hour at 20°C by a Griffin flask shaker set at level 3. pH was determined on an unfiltered portion of the extract and conductivity and nutrient content on a filtered portion. Watman no.4 filter paper was used for an initial rapid filtration followed by filtration through Watman no.1 filter paper. The methods of measuring volumes of growth medium will be described later.

Total and available ammonium-nitrogen and nitrate-nitrogen were determined using a Tecator Kjeltec System 1, using the dry sample for total nitrogen and up to 40mls of the water extract for available nitrogen.

Total and available magnesium, calcium, iron, manganese, copper, zinc, nickel, lead, and cadmium were determined on a Pye-Unicam SP9 atomic absorption spectrophotometer with an air-acetylene flame (81). 0.2% strontium chloride was added to suppress interferences from silicon, phosphorus and aluminium in the determination of magnesium, manganese and

calcium. Aluminium was determined with a fuel rich nitrous oxide-acetylene flame with 0.2% potassium chloride added to prevent ionization of the aluminium.

Total and available sodium and potassium were determined with a Corning 400 flamephotometer and total and available phosphorus spectrophotomically as the yellow phospho-vanado-molybdate complex on a Unicam SP500 Series 2 spectrophotometer. Hydrochloric acid 5M was used to develop the colour. As the water extracts already had slight yellow colouration a deionized water plus hydrochloric acid blank was used and compared to a sample plus water plus hydrochloric acid mixture by measuring the absorbance at 400nm (as for the phosphorus determination, in which sample plus water plus hydrochloric acid plus ammonium molybdate-ammonium metavanadate reagent was used).

The original colour of the extract and the colour formed on addition of the ammonium molybdate-ammonium metavanadate reagent were assumed to be additive, so the water + HCl + sample readings were subtracted from the readings with ammonium molybdate-ammonium metavanadate added.

Some difficulty was found in determining the level of available copper in Levington Potting Compost. A peak reading was obtained on the atomic absorption spectrophotometer which rapidly fell away to zero. Repeated aspirations of the extract following this gave no reading. Deionized water would not clear the 'blockage', but aspiration of a 2ppm solution of copper seemed to do so allowing another peak reading to be reached on aspiration of the extract, but again this fell away rapidly with subsequent aspirations giving no reading. Since the peaks were not

consistent no reading could be recorded. Physical obstruction was ruled out as a cause following thorough cleaning of the instrument and filtering of the extract through a 0.22µm micropore filter. Additions of concentrated hydrochloric, sulphuric or nitric acid gave higher peak readings which very rapidly dropped off, and 0.2% strontium or potassium chloride had similar effects. A few drops of ammonium acetate added to the extract resulted in no reading at all. High available ammonium exists in the Levington Potting Compost extract, but this is unlikely to cause this phenomenon since no major interferences by ammonium have previously been recorded in copper analysis (117).

Total molybdenum and available boron were determined by ADAS at their establishments at StarCross and Exeter, using their own methods for total molybdenum in plant material and available boron in soils (9).

Dry bulk density was initially determined by drying 396cm^3 samples, measured by the 'Settling Equivalent' method, in kilner jars in a forced aeration drying oven at 102°C (± 2°C) for 16 hours. The samples were covered with a tightly fitting lid on removal from the oven and weighed when cool. They were then uncovered and returned to the oven for a further 8 hours, being weighed every 4 hours until the difference between successive weighings was reduced to less than 0.1% of the original weight of the growth medium. 20 hours (total) drying was sufficient for all the growth media.

Measuring the Volume of Growth Media.

The Settling Equivalent Method.

As yet no standard procedure for packing cores of growth media has been widely adopted. Each author has used his own method in order to obtain reproducible results. Some attempt at standardization was made by Verdonck, Cappaert and De Boodt (1978) with the comparison of two methods for the determination of physical characteristics (eg. volume weight, pore volume, volume % water). Mechanical compression of a saturated soil core was used in the first method, with no compression in the second. The seven laboratories which took part in the study produced strikingly different results using the same method and soil type, whilst repeated tests gave fairly consistent results within each laboratory. This shows the difficulty in attempting to develop a standard method for packing soil cores.

The determination of available plant nutrients in growing media requires accurate measurement of a volume of media. Weight cannot be used as the basis for analysis since the media in this study vary greatly in density. The volume of medium in a plantpot is more important in relation to nutrient content than the weight. For total nutrient analysis, accurate measurement of bulk density is necessary since a certain weight of dry material is used. The bulk density can then be used to calculate milligrammes of nutrient per litre of fresh medium. In order to measure bulk density, of course, the volume of the medium must be measured. So, for physical and chemical analyses the production of a repeatable standard volume of growth medium is

important.

An attempt was made to develop a volume measuring system based on the volume to which a growth medium shrinks when watered to saturation and allowed to drain. This procedure itself is of no use in chemical analysis since nutrients would be leached away. Five methods were compared and the 'Settling Equivalent' Method developed from the one which most closely simulated the volume achieved by settling after watering. Spent mushroom compost, worm-worked cow slurry, Kew leafmould, Cambark Fine and Lescost were used as the test media. The growth medium was spread out on a bench and mixed thoroughly, with all large lumps being broken down. It was then put into a plastic bag and left overnight to equilibrate. The moisture content was determined by drying a 100g sample at 102°C for 16 hours, weighing, returning it to the oven and weighing at periodical intervals thereafter until no further weight loss occurred. The following methods were then tested, with 3 replicates per growth medium:-

Method 1 Hanan, Olypios and Pittas (1981).

Equipment:

1 section of square shaped drainpipe 6x6x11cm (vol. 396cm^3).
1 plastic petridish 8.5cm diam.
Masking tape to secure petridish to drainpipe to form base.

The drainpipe was filled loosely with growth medium and struck off level with a straight edge. It was then dropped repeatedly from a height of 1cm onto a bench until no further subsidence of the medium could be observed. The medium subsidence was measured (by measuring the distance from the rim of the pipe to

the medium on each side of the pipe) and the final volume calculated. The growth medium was weighed and the density, (g/cm^3), determined by dividing the weight by the final volume.

Method 2 Bilderback, Fonteno and Johnson (1982)

Equipment:

3 sections drainpipe, 6x6x11cm ($396cm^3$)
1 plastic petridish, 8.5cm diam.
Masking tape to secure petridish to drainpipe and drainpipe sections together.
1 wide-necked $100cm^3$ beaker.

The three cylinders were taped together end to end and the apparatus filled with growth medium in 100cm aliquots using the beaker (loose-filled). The apparatus was dropped 5cm onto the bench following each addition of medium until all three sections of drainpipe were full. The top section was removed by cutting through between the drainpipe and slipping a piece of cardboard into the gap. The middle section was then separated from the bottom section in the same way and the medium in the middle section weighed. The density, (g/cm^3), was determined by dividing the weight by 396.

Method 3 Prasad (1979).

Equipment:

2 sections of drainpipe, 6x6x11cm ($396cm^3$).
1 petridish.
Masking tape.
180g weight to supply a pressure of $5g/cm^2$.

The two sections were mounted on top of one another as in the previous method, loosely filled with medium and struck off level. The weight was placed on the surface of the medium and left for one minute. The top section was separated from the bottom as above and the medium in the bottom section weighed. Density was determined as for method 2.

Method 4 Brown and Pokorny (1975).

Equipment:

2 sections of drainpipe, 6x6x11cm ($396cm^3$).

1 petridish.

Masking tape.

The two sections of drainpipe, taped together as before, were loosely filled with growth medium and struck off level. The side of the bottom section was tapped 40 times using one finger only. The bottom section was separated from the top as before and the medium in the bottom weighed. Density was determined as for method 2.

Method 5 ADAS (10).

Equipment:

1 section of drainpipe, 6x6x11cm ($396cm^3$).

1 petridish.

Masking tape.

The drainpipe was loosely filled with growth medium and struck off level. The medium was weighed, and density determined as for method 2.

The comparison :- Wetted samples.

Equipment:

1 section of drainpipe, 6x6x11cm ($396cm^3$).

1 petridish.

Masking tape.

The drainpipe was loosely filled with growth medium and struck off level. The medium was weighed and water added until it could be seen to have drained down to the petridish. After 18 hours the subsidence was measured and the settled volume of the medium calculated. This volume and the original weight of the medium were used to determine the density in g/cm^3 fresh medium. This was compared with the density calculated for each of the above methods.

The results can be seen in table 2.1.

Growth Medium	Moisture Content w/w	Density (g/cm^3 Fresh Medium) Method 1	Method 2	Method 3	Method 4	Method 5	Wetted
Spent Mushroom	58.5	0.58	0.51	0.41	0.43	0.37	0.48
		0.51	0.54	0.40	0.42	0.37	
		0.52	0.53	0.39	0.42	0.36	
Worm-Worked Cow Slurry	70.8	0.54	0.59	0.46	0.48	0.41	0.51
		0.55	0.58	0.46	0.48	0.42	
		0.55	0.59	0.46	0.48	0.43	
Leafmould	61.0	0.61	0.59	0.42	0.45	0.39	0.49
		0.58	0.63	0.40	0.45	0.42	
		0.56	0.58	0.45	0.43	0.36	
Cambark Fine	45.3	0.35	0.33	0.29	0.29	0.26	0.29
		0.35	0.33	0.27	0.29	0.26	
		0.35	0.33	0.28	0.29	0.26	
Lescost	54.9	0.64	0.70	0.53	0.57	0.50	0.61
		0.65	0.69	0.53	0.56	0.51	
		0.67	0.70	0.53	0.56	0.51	

Comparison of Volume Measuring Methods. Table 2.1

Comparison of Volume Measuring Methods:- Discussion.

The method of Brown and Pokorny (Method 4), although giving consistent results (if a little less dense than the wetted samples) was deemed unsuitable as it was impossible to standardize a 'tap'. It was also very time consuming.

Method 3, which employed the use of a weight to compact the medium, generally gave low densities. This could be remedied with the use of a heavier weight, but not all the media behaved in a similar way under the weight with Cambark Fine reaching the same density as the wetted sample, whilst the others, as stated above, had lower densities than their wetted comparisons.

Method 1 gave difficulties in measuring the subsidence. The distance from the top of the medium to the rim of the drainpipe was measured on each side of the drainpipe and an average used to calculate the decrease in volume. This was complicated by lumps in the medium and uneven subsidence. Subsidence was measured in the same way for the wetted samples, but the water tended to level the surface.

The ADAS method (method 5) did not compact the medium at all with the expected results of low density.

Method 2, although giving relatively high density results, seemed the best basis for a standardized technique. The height of drop could be decreased to give a less densely compacted sample, or larger aliquots of medium added between each drop giving fewer drops per core packed. The height of the drainpipe sections were chosen to be roughly that of an average (12-14cm) size plant pot. This is important since the Settling Equivalent method is supposed to simulate volume after watering, and the

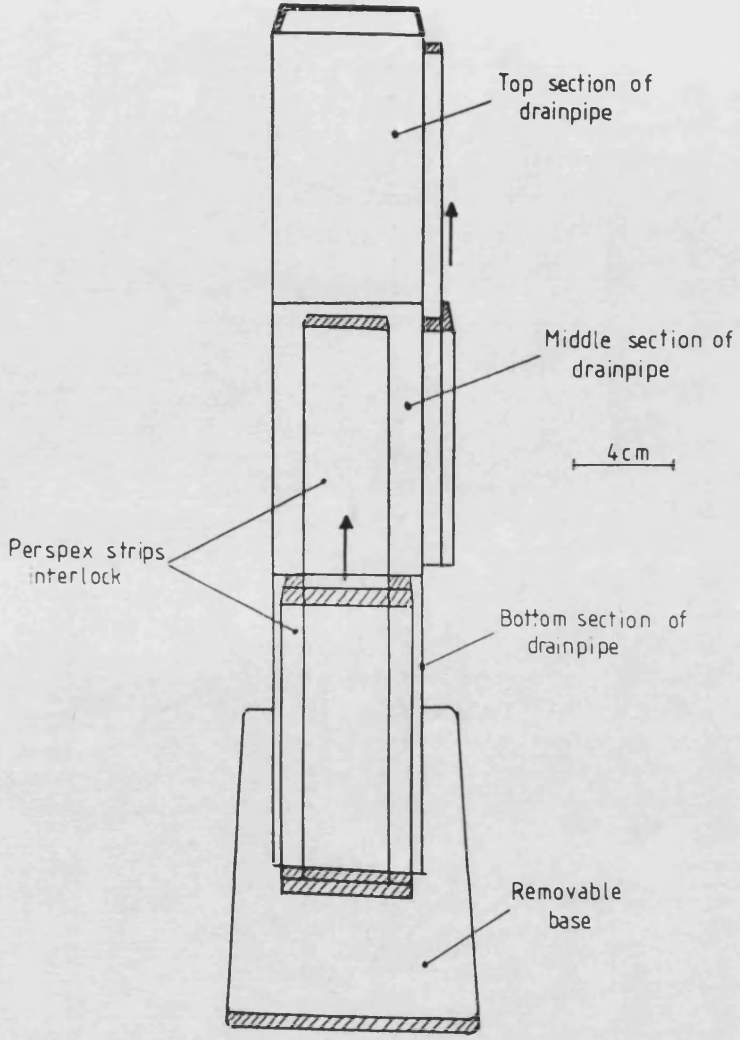
average growth medium density depends on the height of the column of growth medium.

All the experimental growth media were measured using the Bilderback et al method (method 2); dropping the apparatus from a height of 1cm and 3cm. Eight repeats were made at each height, and three replicates were wetted. A new apparatus was designed and built to make the process simpler (figure 2.1). Table 2.2 shows the results.

The density of medium achieved by dropping the apparatus from 1cm seems to simulate quite well that resulting from wetting and settling.

A much greater variation between the recordings was found with leafmould than the other media. This is because of the wide range of particle size and the presence of very dense particles such as stones. To try to reduce this variation as much as possible the leafmould was sieved through a 2cm sieve for all analyses and experiments.

Further experimentation is needed with the Settling Equivalent method to see what effect differing moisture contents have on the degree of compaction. Verdonck et al (1978) suggest that the volume % moisture content has quite a significant influence on the determination of bulk density, and that bulk density should be determined at a volume percentage moisture content of between 50% and 60%.



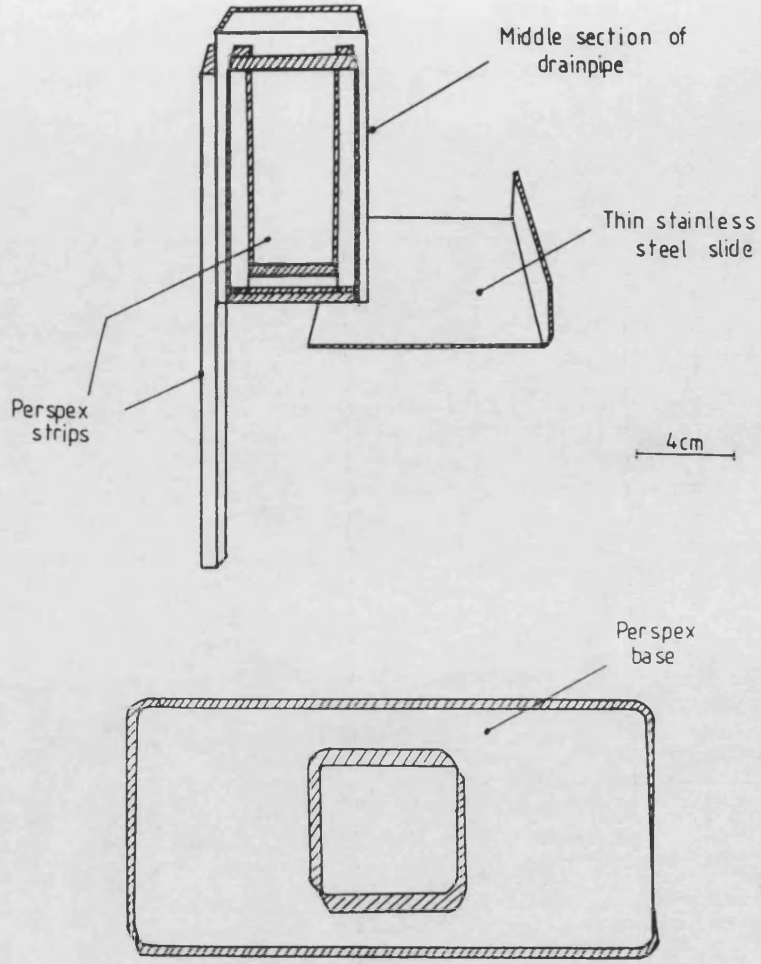


Fig. 2.1 Revised Apparatus for the Settling Equivalent Volume Measuring Method.

Growth Medium	% Moisture Content w/w	Height from which dropped. 3cm Mean g/cm³	3cm SD	1cm Mean g/cm³	1cm SD	Wetted Mean g/cm³
W.W Cow Slurry	73.7	0.586	4.32	0.521	3.25	0.515
Levington Potting	72.9	0.428	2.53	0.390	4.32	0.383
W.W. Pig Slurry	69.0	0.558	3.42	0.511	2.57	0.493
Cambark Fine	40.5	0.295	2.22	0.278	2.25	0.274
Lescost	52.4	0.655	2.42	0.603	3.91	0.595
Leafmould	58.3	0.525	9.04	0.477	8.25	0.467
Spent-Mushroom	63.7	0.497	4.91	0.443	2.71	0.465
Sedge Peat	73.4	-	-	0.532	1.17	0.529

Volume Measuring- 'Bilderback' Method. Table 2.2

Measuring the Volume of Growth Media

The FIBSPAN Method

Since the initiation of this project new information makes the 'Settling Equivalent' method of measuring the volume of growth media obsolete. Fisons, in conjunction with other members of the Peat Producers Association (U.K.) Ltd. have developed the FIBSPAN method (Fisons British Standard Peat Afnor Normes) and accepted it as standard (Appendix 1). For this reason, all chemical analyses undertaken after December 1984 were based on this method. It should be noted that the bulk densities recordeed with this method are lower than those with the 'Settling Equivalent' method, and further reduction in the volume of most media occurs on wetting. The results of chemical analyses based on the FIBSPAN litre will thus be lower than for the 'Settling Equivalent' method.

Physical Properties of Growth Media

The following physical properties were investigated:-

Dry Bulk Density.

Wet bulk Density (at saturation and container capacity).

Water holding capacity (at saturation and container capacity).

Percentage volume of air at container capacity.

Dry bulk density was measured as described previously, this time using the FIBSPAN volume measuring method. Wet bulk density, water holding capacity and percentage volume of air at container

capacity were determined using a single method based on the method of White and Mastalerz (1966), and later on that of Goh and Maas (1980). Emphasis was placed on simplicity during all these determinations. All media were mixed, with large lumps (those significantly larger than the average) being broken down, and left overnight in a closed container to equilibrate before use.

Method 1 (White and Mastalerz, (1966)).

Equipment

1. 1 FIBSPAN Apparatus.
2. 3x1 litre cylinders to fit the FIBSPAN apparatus per medium with perforated bases to allow free drainage (eg 10.5 cm internal diam. x 12 cm height with 17x5mm diam. holes in the base).
3. No. 1 Whatman filter paper cut to cover the base of the cylinders.
4. Lid or film (parafilm is best) to prevent evaporation.
5. Glass sheet 12 x 12 cm covered tightly with a piece of plastic bag and sealed with tape.
6. Petri dish lids (2 per cylinder).
7. 1 Washing-up bowl per cylinder.
8. Wire grid big enough to sit on the rim of the bowl.
9. Growth Medium.
10. 2 strong, large, elastic bands.

Method

1. Weigh the cylinders and label accordingly. Weigh the glass and covering.

2. Line the base of the cylinders with the filter paper cut to size. Moisten one representative piece of filter paper and weigh.

3. Fill the cylinders with growth medium according to the FIBSPAN method and weigh, then cover the cylinders with lid/film and weigh again.

4. Place the petri dish lids inverted into the bowl and arrange them so that one cylinder can be stood firmly on them whilst allowing water to enter freely.

5. Fill the bowl slowly with water to within 1/2 cm of the top of the cylinders. Do not allow the cylinders to float. Leave for 24 hours.

6. Slide the glass and covering under each cylinder in turn and secure with elastic bands. Carefully remove to a balance so that no water excapes from the cylinder. Dry the outside of the cylinder as much as possible. Record the weight. This part of the procedure proved somewhat difficult to achieve and led to the modifications in method 2.

7. Place the grid over the bowl and allow the cylinders to drain

for 24 hours or until drainage ceases - the time required to drain to container capacity will vary with the medium used.

8. Repeat steps 4-7.

9. Transfer the cylinders to the balance and weigh. Remove lids and measure the shrinkage: Take four measurements from the rim of the cylinder to the growth medium and calculate the mean depth of the medium from the rim. Use this to calculate the volume of medium at container capacity from the equation below:-

$$\text{Volume } (cm^3) = 1000 - \pi r^2 h$$

Where h= mean depth of medium from rim (cm)

and r= radius of cylinder (cm).

10. Transfer the medium quantitatively to an oven proof dish and dry in a forced aeration oven for 24 hours at 102°C or until constant weight is reached. Kilner jars are good for this as they can be allowed to cool with the lids on eliminating the need for a desiccator.

Calculations

(1) Weight of cylinders, (g).

(2) Weight of glass + covering, (g).

(3) Weight of moist filter paper, (g).

(4) Wt. of medium + cylinder + filter paper.

(5) Wt. of medium + cylinder + lid + filter paper.

(6) (5)-(4)-(3) Wt. of lid.

(7) Wt. of medium + cylinder + glass + lid + filter paper at saturation.

(8) (7)-(6)-(3)-(2)-(1) Wt. of medium at saturation.

(9) Wt. of medium + cylinder + glass + lid + filter paper at container capacity.

(10) (9)-(6)-(3)-(2)-(1) Wt. of medium at container capacity.

(11) Volume of medium at container capacity.

(12) Dry wt. of medium.

All the following are based on settled volume at container capacity:

(a) DRY BULK DENSITY = Dry wt. (12)/Volume (11) g/l

(b) BULK DENSITY ON SATURATION = Wt. at saturation (8)/
Volume (11) g/l

(c) BULK DENSITY AT CONTAINER CAPACITY =
Wt. at container capacity (10)/ Volume (11) g/l

(d) TOTAL WATER HOLDING CAPACITY = Wt. at saturation (8) -
Dry wt. (12) g=cc

(e) WATER CONTENT AT CONTAINER CAPACITY =

Wt. at container capacity (10) - Dry wt. (12) g=cc

(f) APPROX. AIR SPACE AT CONTAINER CAPACITY =

Total water holding capacity (d) - Water content at container capacity (e) cc .

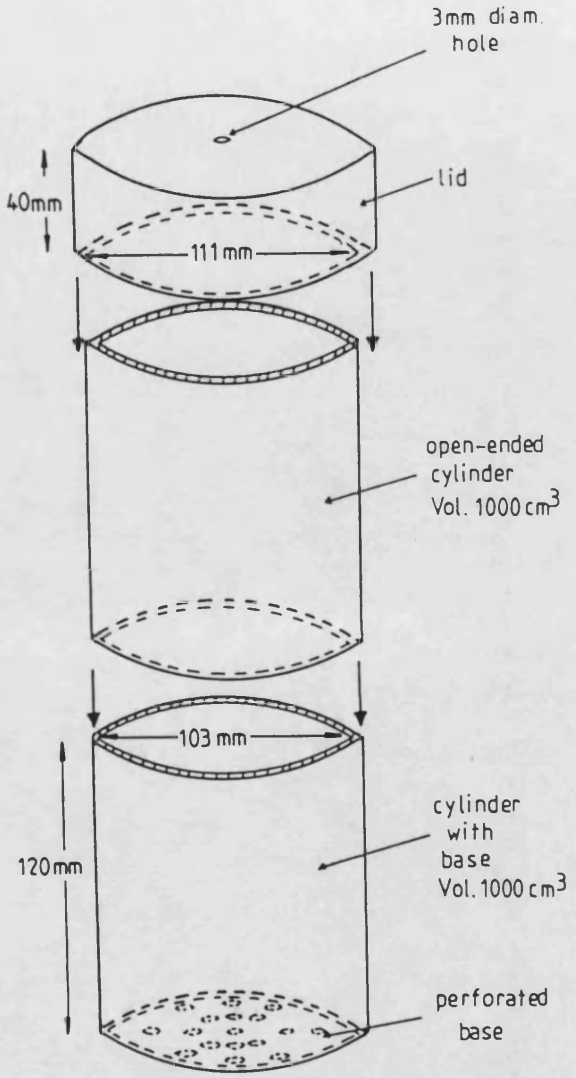
N.B. The FIBSPAN litre gives a lower bulk density than that of many growth media under practical growing conditions (i.e. it shrinks to less than 1 l on wetting). For this reason the above calculations have been based on the settled volume. Nutrient analyses based on the FIBSPAN method will therefore give results lower than those encountered in the plant pot. This has been the case for sometime with Ministry analyses based on a loose fill method of volume measuring which gives an even lower bulk density. All present fertilizer recommendations are based on the latter. Results of nutrient analyses based on the FIBSPAN method could be adjusted to the settled volume if desired.

Owing to difficulties encountered in the removal of saturated samples from the bowls and in measuring the exact volume of medium after shrinkage the following method was developed.

Method 2 (White and Mastalerz (1966) and Goh and Maas (1980)).

Equipment

1. 1 FIBSPAN apparatus.
2. 3x1 litre open-ended cylinders per medium.
3. 3x1 litre cylinders with perforated bases to allow free drainage (eg 10.5 cm internal diam. x 12 cm height with 17 x 5mm diam. holes in base).
4. No. 1 Whatman filter paper cut to cover the base of the cylinders.
5. 1 tight fitting lid with one 3mm diam. hole in centre per cylinder with base.
6. Insulation tape.
7. Petri dish lids.
8. 1 large bucket per cylinder with base.
9. Wire grid big enough to sit on the rim of the bucket.
10. Growth medium.
11. Film to prevent evaporation.



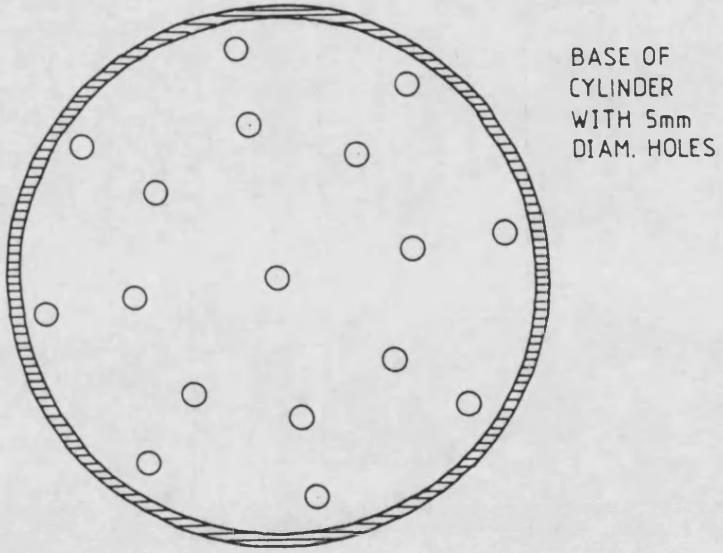


Fig. 2.2 Apparatus for Physical Analysis Method 2, (White & Mastalerz (1966) and Goh & Maas (1980)).

Method

1. Weigh the cylinders with bases and label accordingly. Weigh the lid.

2. Line the bases of the cylinders with the filter paper cut to size. Moisten one representative piece of filter paper and weigh.

3. Attach the open-ended cylinders to the tops of the cylinders with bases with the insulation tape to form double cylinders.

4. Fill the cylinders with growth medium according to the FIBSPAN method; do not compress with the weight. Cover the cylinders with film.

5. Place the petri dish lids inverted into the bucket and arrange them so that one double cylinder can be stood firmly on them whilst allowing water to enter the cylinders freely.

6. Fill the bucket slowly with water to within 1/2 cm of the top of the growth medium. Do not allow the cylinders to float. Leave for 12 hours.

7. Remove the cylinders from the bucket and allow to drain on the wire grid for 12 hours.

8. Repeat 5 - 7 twice more.

9. Separate the two cylinders with a sharp knife and retain the bottom one.

10. Level the top of the sample and cover with the close fitting lid.

11. Submerge the cylinder completely in water. Push the lid down firmly to exclude all air from underneath. Invert the cylinder to allow easier release of air. Leave for one hour.

12. Push the lid down firmly again.

13. Place a finger over the hole and remove the cylinder from the water. Dry the outside and weigh.

14. Place the grid over the bucket and allow the cylinders to drain for 12 hours. Loosen the lids a little to allow air in freely, whilst limiting water loss by evaporation.

15. Transfer the cylinders to the balance and weigh.

16. Transfer the medium quantitatively to oven proof dishes and dry in a forced aeration oven for 96 hours at 102 ^{o}C or until constant weight is reached. Kilner jars are good for this as they can be allowed to cool with the lids on eliminating the need for a desiccator.

Calculations

(1) Weight of cylinders with bases, (g).

(2) Weight of lids, (g).

(3) Weight of moist filter paper, (g).

(4) Wt. of medium + cylinder + lid + filter paper at saturation.

(5) (4)-(3)-(2)-(1) Wt. of medium at saturation.

(6) Wt. of medium + cylinder + lid + filter paper at container capacity.

(7) (6)-(3)-(2)-(1) Wt. of medium at container capacity.

(8) Dry wt. of medium.

All the following are based on settled volume at container capacity:

(a) DRY BULK DENSITY = Dry wt. (8)/1000 g/l

(b) BULK DENSITY ON SATURATION = Wt. at saturation (5)/1000 g/l

(c) BULK DENSITY AT CONTAINER CAPACITY = Wt. at container capacity (7)/1000 g/l

(d) TOTAL WATER HOLDING CAPACITY = Wt. at saturation (5) - Dry wt. (8) g=cc.

(e) WATER CONTENT AT CONTAINER CAPACITY = Wt. at container capacity (7) - Dry wt. (8) g=cc.

(f) APPROX. AIR SPACE AT CONTAINER CAPACITY =

Total water holding capacity (d) - Water content at container capacity (e) cc

Leaf Analysis.

Leaf samples were prepared using the method of dry combustion already described for growth media (page44), with the following alterations:-

1. Leaves were washed and dried as described in the section entitled 'Growth Trials' (page87) prior to grinding.
2. Only 2 hours total ashing was found to be necessary.
3 The following elements were determined, using the methods employed for growth media, the results being quoted in mg/g dry matter of µg/g dry matter (ppm).(N.B. 1mg/g = 0.1%.) :-

Phosphorus.

Potassium.

Magnesium.

Iron.

Copper.

Zinc.

Results, Discussion and Characterization of Growth Media

Relationships Between Bulk Density Measuring Methods

The bulk densities (mg dry matter/l fresh medium) as determined by the Settling Equivalent volume measuring method, the method 2 for physical properties (based on White and Mastalerz (1966) and Goh and Maas (1980)) and the FIBSPAN method were found to be related as follows:-

Settling Equivalent vs FIBSPAN Bulk Density

A correlation significant at the P=0.001 level was found to exist between the two methods (r^2 =98.0%) where:-

FIBSPAN BD = 0.901 Settling Equivalent BD - 1.4

This equation can therefore be used to convert nutrient contents based on the Settling Equivalent litre to the FIBSPAN litre (see table 2.4).

Method 2 for Physical Properties vs FIBSPAN Bulk Density

These two methods were also significantly correlated at the P=0.001 level (r^2=95.8%).

FIBSPAN BD = 0.769 Method 2 BD - 3.9

The FIBSPAN method of measuring volume therefore relates by these equations to the settled volume following watering. The FIBSPAN litre is evidently less dense than that of both the other methods, and

Method 2 is probably more dense than would be experienced in the plant pot because the lower of two cylinders is used in this method. Since all the methods correlated well with each other conversions can be made to analytical results to give more realistic results if required.

FIBSPAN vs. ADAS Loose Fill Method

These two methods of measuring volume of peat substrates were found to be related by an approximate relationship as follows:- (The FIBSPAN 11 container was used to measure 3 replicates of 3 peat based media for each method).

$$\text{Loose fill} = 0.873\text{FIBSPAN}$$

Analytical Results and Characterization of Media

The total and available nutrient levels are given in tables 2.3 to 2.8. The media are divided into two groups:-

1984 Media - those used in the tomato trial and the first chrysanthemum trial.

1985 Media - those used in chrysanthemum trial 2, the nursery stock trial, the shrinkage trial and the seedling trials (unless otherwise stated).

The same batches of leafmould, bark and spent mushroom compost were used in both years. The 1985 results thus represent any changes which occurred to the media over the period of a year. The major changes were substantial increases in bulk density for leafmould and spent mushroom compost which would result in increased nutrient content results, and decreased total porosity. Since particle size is likely to be decreased this may result in an increased water holding capacity and decreased volume

percent air (Handreck (1983) and Jinks (1986)).

All nutrient analyses for 1984 were based on the Settling Equivalent litre. These have been converted to the FIBSPAN litre bases using the equation above and can be seen in table 2.4. Total nutrients are also quoted in percentage dry matter, since this measure has been widely used by other authors.

The physical properties can be seen in table 2.9 These are based on the method 2 for physical properties described on p62.

1984 MEDIA

Medium	Al	Ca	Cd	Cu	Fe	K	Mg	Mn
Leafmould	495	9072	0.14	7.7	2680	757	443	111.2
Cambark Fine	87	2001	0.08	1.0	293	277	78	38.6
Lescost	2206	11835	0.88	111.2	5641	1811	1254	84.8
Mushroom	122	23374	0.11	5.7	824	3222	709	56.0
Levington Potting	51	5955	0.04	8.9	315	342	1100	21.5
W.W. Pig Slurry	278	17898	0.11	412.0	1711	1799	1285	103.4
W.W. Cow Slurry	208	4534	0.08	17.7	1032	651	256	45.5
Sedge Peat	250	3765	0.04	1.2	1212	97	291	22.6

Medium	Mo *	Na	Ni	N	P	Pb	Zn	Dry Bulk Density g/l
Leafmould	0.78	87.7	11.6	2425	428	47.2	30.9	204.0
Cambark Fine	0.43	24.1	7.8	555	68	2.0	5.8	163.5
Lescost	4.03	2304.8	28.8	3495	999	189.0	286.4	263.4
Mushroom	0.30	341.5	3.2	2976	1113	4.8	367.4	164.2
Levington Potting	0.87	39.2	1.0	1162	261	1.6	2.9	111.1
W.W. Pig Slurry	0.96	240.9	9.0	5536	4459	4.4	260.4	208.6
W.W. Cow Slurry	0.15	80.0	10.8	2772	618	2.7	92.4	157.7
Sedge Peat	0.41	26.9	1.4	2145	109	2.3	5.2	137.9

* measured by ADAS

TOTAL NUTRIENTS mg/l FRESH MEDIUM BASED ON THE SETTLING EQUIVALENT LITRE. TABLE 2.3

Medium	Al	Ca	Cd	Cu	Fe	K	Mg	Mn
Leafmould	410.4	8111	0.13	6.8	2396	677	396	99.4
Cambark Fine	77.3	1785	0.07	0.9	261	247	70	34.5
Lescost	1976.0	10599	0.78	99.5	5052	1622	1123	76.0
Mushroom	109.0	20854	0.10	5.1	735	2875	633	49.9
Levington Potting	45.0	5290	0.03	7.9	279	304	977	19.1
W.W. Pig Slurry	248.5	16002	0.10	368.0	1530	1609	1149	92.5
W.W. Cow Slurry	185.5	4045	0.07	15.8	920	580	228	40.6
Sedge Peat	222.6	3352	0.04	1.1	1079	87	259	20.1

Medium	Na	Ni	N	P	Pb	Zn	Dry Bulk Density mg/l
Leafmould	78	10.4	2168	383	42.2	27.6	182.4
Cambark Fine	22	6.9	495	61	1.8	5.2	145.9
Lescost	2064	25.8	3130	895	169.3	256.5	235.9
Mushroom	305	2.9	2655	993	4.2	327.8	146.5
Levington Potting	35	0.9	1032	232	1.4	2.5	98.7
W.W. Pig Slurry	215	8.1	4949	3986	3.9	232.7	186.5
W.W. Cow Slurry	71	9.6	2473	551	2.4	82.5	140.7
Sedge Peat	24	1.2	1910	97	2.1	4.7	122.8

TOTAL NUTRIENTS mg/l FRESH MEDIUM BASED ON THE FIBSPAN LITRE. TABLE 2.4

Medium	Al %	Ca %	Cd ppm	Cu ppm	Fe %	K %	Mg %	Mn ppm
Leafmould	0.23	4.5	0.69	38	1.30	0.37	0.22	545
Cambark Fine	0.05	1.2	0.49	6	0.20	0.17	0.05	236
Lescost	0.84	4.5	3.34	422	2.10	0.69	0.48	322
Mushroom	0.07	14.2	0.70	35	0.50	1.96	0.43	341
Levington Potting	0.05	5.4	0.36	80	0.30	0.31	0.99	194
W.W. Pig Slurry	0.13	8.6	0.53	1975	0.82	0.86	0.62	496
W.W. Cow Slurry	0.13	2.9	0.51	112	0.65	0.41	0.16	289
Sedge Peat	0.18	2.7	0.29	9	0.88	0.07	0.21	164

Medium	Mo ppm	Na %	Ni ppm	N %	P %	Pb ppm	Zn ppm
Leafmould	3.80	0.04	56.9	1.2	0.21	231.4	151.0
Cambark Fine	2.60	0.01	47.7	0.3	0.04	12.2	35.5
Lescost	15.30	0.88	109.3	1.3	0.38	717.5	1087.3
Mushroom	1.83	0.21	19.5	1.8	0.68	29.2	2240.0
Levington Potting	7.83	0.04	9.0	1.1	0.23	14.4	26.1
W.W. Pig Slurry	4.60	0.12	43.1	2.7	2.14	21.1	1248.3
W.W. Cow Slurry	0.95	0.05	68.5	1.8	0.39	17.1	585.9
Sedge Peat	2.97	0.02	10.2	1.6	0.08	16.7	37.7

TOTAL NUTRIENTS - DRY MATTER BASIS TABLE 2.5

Medium	Al	B *	Ca	Cd	Cu	Fe	K	Mg	Mn
Leafmould	3.00	8.48	84	0.000	0.20	4.35	288	7.5	0.24
Cambark Fine	0.15	0.62	45	0.000	0.20	0.33	138	3.1	0.06
Lescost	1.05	11.38	858	0.093	0.75	2.37	1212	105.0	0.23
Mushroom	0.00	2.08	1605	0.015	0.54	0.93	2880	182.1	0.62
Levington Potting	0.90	1.06	342	0.000	?	0.57	270	79.8	0.80
W.W. Pig Slurry	0.30	6.82	1026	0.000	1.61	0.12	1494	458.4	0.48
W.W. Cow Slurry	0.00	3.18	303	0.000	0.32	0.39	532	41.3	0.09
Sedge Peat	0.00	3.70	171	0.006	0.24	0.78	7	12.0	0.03

Medium	Na	Ni	N	NH4+-N	NO3 -N	P	Pb	Zn	pH	us/cm
Leafmould	52.5	0.12	9	8.6	0.0	13.0	0.00	0.11	8.03	258
Cambark Fine	29.4	0.00	0	0.0	0.0	13.7	0.00	0.03	6.78	118
Lescost	1252.8	0.30	987	25.7	961.5	4.3	0.36	0.84	7.65	2178
Mushroom	366.0	0.00	548	60.0	487.5	33.0	0.00	2.94	7.88	2548
Levington Potting	46.2	0.00	1376	1200.0 +	175.5	141.0	0.00	0.11	5.33	677
W.W. Pig Slurry	223.2	0.03	1232	77.1	1155.0	228.0	0.00	0.47	6.23	2343
W.W. Cow Slurry	70.8	0.00	711	0.0	711.0	69.0	0.00	0.37	6.58	630
Sedge Peat	39.6	0.00	68	0.0	67.5	6.0	0.00	0.09	5.35	122

* measured by ADAS

AVAILABLE NUTRIENTS mg/l FRESH MEDIUM BASED ON THE SETTLING EQUIVALENT LITRE. TABLE 2.6

+ This abnormally high figure for NH4+-N is possibly caused by rapid formation of NH4+ from urea formaldehyde under analysis conditions. This level of NH4+ would not be present in the pot as urea formaldehyde has slow release properties.

Medium	Al	Ca	Cd	Cu	Fe	K	Mg	Mn
Leafmould	2.70	76	0.000	0.18	3.92	260	6.8	0.22
Cambark Fine	0.14	40	0.000	0.18	0.30	124	2.8	0.05
Lescost	0.95	773	0.084	0.68	2.14	1092	94.6	0.21
Mushroom	0.00	1446	0.014	0.49	0.84	2595	164.1	0.56
Levington Potting	0.81	308	0.000	?	0.51	243	71.9	0.72
W.W. Pig Slurry	0.27	924	0.000	1.45	0.11	1346	413.0	0.43
W.W. Cow Slurry	0.00	273	0.000	0.29	0.35	479	37.2	0.08
Sedge Peat	0.00	154	0.005	0.22	0.70	7	10.8	0.03

Medium	Na	Ni	N	NH4+-N	NO3 -N	P	Pb	Zn	us/cm
Leafmould	47.3	0.11	8	7.7	0.0	11.7	0.00	0.10	233
Cambark Fine	26.5	0.00	0	0.0	0.0	12.3	0.00	0.03	106
Lescost	1128.8	0.27	890	23.2	866.3	3.9	0.32	0.76	1962
Mushroom	329.8	0.00	493	54.1	439.2	29.7	0.00	2.65	2295
Levington Potting	41.6	0.00	1239	1081.2	158.1	127.0	0.00	0.10	610
W.W. Pig Slurry	201.1	0.03	1110	69.5	1040.7	205.4	0.00	0.42	2111
W.W. Cow Slurry	63.8	0.00	641	0.0	640.6	62.2	0.00	0.33	567
Sedge Peat	35.7	0.00	61	0.0	60.8	5.4	0.00	0.08	109

AVAILABLE NUTRIENTS mg/l FRESH MEDIUM BASED ON THE FIBSPAN LITRE. TABLE 2.7

1985 MEDIA

Medium	Ca	Cd	Cu	K	Mg	Ni	N	NH4+-N	NO3 -N	P	Pb	Zn	pH	us/cm	
Leafmould	122			305	12.8		83	20.1	63.3	7.2			6.88	284	
Cambark Fine	38			131	3.0		34	14.3	19.6	9.1			6.00	117	
Mushroom	1704			3090	207.0		289	16.5	272.7	27.3			7.05	2675	
W.W Pig	256			1710	278.7		111	17.9	93.2	228.5			6.30	1530	
W.W Cow	132			1644	67.1		438	2.2	435.4	95.8			7.08	1127	
Doncaster	672			287	72.0	0	275	18.8	255.9	3.1	0	0.24	7.03	907	
Sphagnum Peat	16	0.00	0.00	3	2.5	0	54	29.9	23.8	0.8	0	0.06	3.40	43	
Levington Universal													5.35	395	
Pig slurry Compost	764		0.96	1416	178.2		522	453.0	69.0	228.0		0.56	6.20	1240	
Beech Leafmould													7.73	154	
Doncaster															Dry Bulk Density
TOTAL FIB.	19874	1.21	99.4	838	1365	42.9				2837	147	302			366.0g/l
D.M.	5.43%	3.3ppm	271ppm	0.23%	0.37%	117ppm				0.77%	403ppm	825ppm			

1985 MEDIA. AVAILABLE NUTRIENTS mg/l FRESH MEDIUM BASED ON THE FIBSPAN LITRE. TABLE 2.8

MEDIUM	DRY BULK DENSITY g/l	SATURATED BULK DENSITY g/l	BULK DENSITY CONTAINER CAPACITY g/l	WATER CONTENT SATURATION cm^3	WATER CONTENT CONTAINER CAPACITY cm^3	AIR SPACE CONTAINER CAPACITY cm^3	VOL. % AIR AT CONTAINER CAPACITY
Levington Universal	319.9	1101.3	1076.3	781.4	756.4	25.0	2.50
Levington Potting	145.3	969.7	910.9	822.4	756.6	58.8	5.88
Sphagnum Peat	115.7	891.0	851.9	775.3	736.2	39.1	3.91
Sedge Peat	182.9	1056.2	1024.0	873.3	841.1	32.2	3.22
Cambark Fine	180.8	911.6	586.4	730.8	405.6	325.2	32.52
Kew Leafmould	395.2	1208.4	1181.6	813.2	786.4	26.8	2.68
Beech Leafmould	114.1	1000.6	730.5	886.5	616.4	270.1	27.01
W.W Cow Slurry (85)	135.3	1048.2	1021.3	912.9	886.0	26.9	2.69
W.W Pig Slurry (85)	236.1	1065.1	995.3	829.0	759.2	69.8	6.98
Pig Slurry Compost	160.3	962.8	921.3	805.2	761.0	41.5	4.15
Spent Mushroom	288.5	1052.2	987.9	763.7	699.4	64.3	6.43
Lescost	360.5	1118.4	995.6	757.9	635.1	122.8	12.28
Doncaster Compost	483.6	1196.9	1107.0	713.3	623.4	89.9	8.99

Physical Properties of Growth Media Table 2.9

Characterization of the Media

Appendix 2 shows the total nutrient content of sphagnum peat, and the recommended levels of nutrient addition to sphagnum peat for various purposes. Appendix 3 gives the desirable indices for crops grown in loamless media and the classification system used. The results from the analyses of the experimental media (tables 2.3 to 2.8) can be compared with these appendices to give some indication of the biological significance of their nutrient contents. It must be remembered though, that physical and physico-chemical properties of the media such as water holding capacity, cation exchange capacity, conductivity, pH and the balance of nutrients will affect the availability of each nutrient to the growing plant. For instance, high levels of nitrogen and potassiom relative to phosphorus may give rapid growth resulting in phosphorus deficiency. Potassium-magnesium antagonism is well ducumented with high potassium levels causing magnesium deficiency and vice versa (Bunt 1976). Also the lower the amount of nutrient fixation onto a medium the greater the availability of the nutrients (provided they are not leached away). The ion fixation rate, cation exchange capacity and water holding capacity combined with feeding and watering rate (and initial nutrient content) will determine the quantity of nutrients available following an addition of fertilizer.

A brief list of interactions between nutrients is given in Appendix 4 . The extraction method used for available nutrients may also make the interpretation of the results more difficult; possibly bearing a greater relation to plant uptake in one medium than another. Studies with plant analysis in addition to

medium analysis are presented later to discover if there is a constant relationship between plant uptake and the water extraction of nutrients for all the media.

Each medium is discussed individually in the following pages. These comments and predictions are based on a comparison with the recommended indices for loamless media (mainly peat or peat/sand mixtures) and on interactions between nutrients previously noted for plants growing in loam and peat based media. It is therefore conceivable that the optimal balance of nutrients in the organic waste composts may be very different from that for peat and loam media. The following notes must be read with this view in mind. Correlations of growth response with media nutrient contents are presented later, in an attempt to determine whether growth can be predicted from the analytical methods used here, on such a wide range of organic waste media.

Note on Terminology The term 'compost' is used loosely within the horticultural industry to mean a substance used as a growth medium. In this study the latter expression is preferred since many of the organic wastes are true 'composts' in that they have been produced by the method of composting.

1984 Media

Lescost (Ls)

This compost is high in total and available macronutrients, but low in available phosphorus. The total micronutrient level is high, but the availability is low with the exception of boron. This may result in boron toxicity problems in crops.

The total and available heavy metal content is much greater than that of peat media which could result in accumulation of these elements to zootoxic levels in edible crops.

The conductivity is very high leading to likely salinity problems and the pH is also high at 7.65 which would depress availability of phosphorus, manganese, magnesium, boron, copper, and zinc. This compost would not be suitable for calcifuges.

The nutrient content of this compost may vary greatly from batch to batch.

The water holding capacity is a little lower than that of sphagnum peat and the volume percent air somewhat higher. This may result in a slightly higher rate of drying out.

Practical Handling

The dry bulk density is very high giving a very heavy compost.

Small pieces of broken glass in the compost may cause problems with handling, but otherwise this is a pleasant, odourless, granulated compost.

It has been suggested that shrinkage in the pot may be a problem (145).

Cambark Fine (B)

This medium is very low in total and available macro and micronutrients. The heavy metal content is extremely low so this is a safe medium for edible crops. The conductivity is low so there are no salinity problems, but the pH is a little high causing a possible decrease in the availability of phosphorus, manganese, boron and zinc. The available K:Mg ratio is 44:1. This will undoubtably result in magnesium deficiency unless the balance is redressed.

A full range of fertilizers is required for pot plant use.

Practical Handling

The dry bulk density is quite low so carrying the medium is not a problem. It is relatively pleasant to handle, but splinters may be received. Watering is required frequently as the water holding capacity is very low at 406 cm^3/l and the volume % air high (32.5%). This would result in wastage of liquid feed as frequent feeding would be required and base dressing would be lost by leaching.

Spent Mushroom Compost (M)

Macronutrient levels (both total and available) are very high in this medium, but a high K:Mg ratio may result in magnesium deficiencies. Total micronutrient levels are moderately high, with zinc being particularly high, and molybdenum an exception in being low. Availability of micronutrients is quite low.

Heavy metal levels are low being only slightly higher than for Levington Potting Compost.

Conductivity and pH are both very high resulting in

subsequent salinity causing stunting of plants and a depressive effect on the availability of phosphorus, manganese, iron, magnesium, boron, copper and zinc. Depression of magnesium levels would further increase the K:Mg ratio.

Practical Handling

The dry bulk density is medium. It is rather a sticky messy compost and the presence of undegraded straw may cause excessive shrinkage in the pot as it breaks down. Stokes (1976) found that the longer the compost was stored before use the less the shrinkage, but that more nitrogen must be added, and Henny (1979) suggested adding 30% pinebark to reduce shrinkage.

The water holding capacity is adequate, and the volume percent air slightly higher than for Levington Potting compost.

Kew Leafmould (Lf)

This particular leafmould contains moderate total levels of most nutrients, but they are relatively unavailable. Magnesium is particularly unavailable and the available K:Mg ratio of 40:1 combined with a high pH of >8, which will depress phosphorus, magnesium, iron, manganese, boron, copper and zinc levels, will probably result in magnesium deficiency. The heavy metal levels are quite high, particularly for lead, but little is available.

A low conductivity and low availability of nutrients would make this medium suitable for seeds, but it is not suitable for calcifuges. Fertilizers must be added for use as a potting medium. The reserve of nutrients may become available in time which could suggest that the leafmould would be

useful as nursery stock medium.

Practical Handling

The dry bulk density is high owing to the presence of stones and twigs, but the larger ones can be removed by sieving through a 20mm sieve. This also removes other contaminants such as dog faeces and rubbish collected along with the leaves. The former are not unpleasant after two years of composting, but do not mix in with the leafmould and remain in lumps.

Watering is required as frequently as for sphagnum peat, as the water holding capacity and air capacity are similar. Weed growth is a problem in pot plants.

This medium will continue to break down with time, with increased bulk density and water holding capacity and decreased air capacity the likely result.

Levington Potting Compost (Lv or LvP)

This is high in available macronutrients with much of the total being available. It has a moderate total level of micronutrients with low availability, but compared to the other media, the percentage of total which is available is quite high.

The heavy metal content is very low.

The conductivity is suitable for a new medium, but not for salt sensitive plants or seeds. The pH is optimal.

Practical Handling

The dry bulk density is very low and therefore the medium is easily carried, but when pots dry out the plants are easily knocked over.

It is clean and pleasant to handle. Watering is

required quite frequently. Shrinkage away from the sides of the pot can be a problem.

Sedge Peat (S)

Sedge peat is low in all macro- and micronutrients, both total and available with the exception of available boron which is quite close to toxicity levels. The heavy metal content is low. The very low availability of manganese may cause some iron deficiency.

The conductivity is very low and pH optimal. This would be suitable for seeds, or with fertilizer added, pot plants.

Practical Handling

The dry bulk density is only a little higher than that of Levington Potting Compost with the same advantages and disadvantages of ease of carrying but instability of pot plants when the medium is dry.

Weed growth may be a problem and also shrinkage away from the side of the pot. Watering frequency will be less than for sphagnum peat as the waterholding capaciy is high. Volume percent air seems adequate when compared to sphagnum peat.

Worm-Wormed Pig Slurry (P or P84)

Very high total and available macronutrients are present in this medium. Total micronutrient levels are generally high, especially copper. Boron availability is very high. The slightly high pH will tend to decrease this availability, possibly preventing toxicity.

The total nickel level is quite high (nine times that of Levington Potting Compost) but it is relatively unavailable. Other heavy metal concentrations are very low.

High phosphorus and nitrate may lead to molybdenum and iron deficiencies, but the latter has good reserves. High nitrate may make this medium unsuitable for leafy food crops.

The conductivity at 2342.5 µs/cm makes salinity problems inevitable. This medium cannot be used in it's neat state.

The nutrient content of this medium will vary from batch to batch (see 1985 batch analysis).

Practical Handling

The dry bulk density is quite high so the medium is very heavy.

Worms in the moist medium may be regarded as a problem for handling purposes, but these can be killed by reducing the moisture content to below 60% v/v. This does not erradicate them completely as cocoons will hatch when rewetted (55).

Water holding capacity and volume percent air are similar to those of Levington Potting Compost (P85 figures). These, however, will vary depending on the degree of decomposition and size of particles.

Worm-Worked Cow (Cattle) Slurry (C or C85)

Very high levels of available nitrate and phosphorus are present, moderate levels of potassium and calcium, but a relatively low level of magnesium. The high K:Mg ratio could well result in magnesium deficiency. Boron toxicity is possible, but the high

pH will reduce boron availability (along with that of phosphorus, manganese, copper, and zinc).

Total micronutrient levels are quite high, except for that of molybdenum which is very low. The availability of the micronutrients is moderate, except for Mn which is low. Iron deficiency may be caused by high phosphate and nitrate levels and by a high K:Ca ratio. Low manganese availability coupled to the high pH which further reduces the availability will also tend to reduce iron uptake. High nitrate will have a depressive effect on molybdenum availability which is already very low. This may result in deficiency symptoms. The conductivity is reasonable for a new growth medium or for more salt tolerant species.

The nutrient content of this medium will vary from batch to batch (see 1985 batch analyses).

Practical Handling

The dry bulk density is roughly equal to that of bark, and slightly higher than for sphagnum peat. Watering is needed less frequently than for peat, the water holding capacity being high (P85 figures).

The texture is fine and particle size even. Worms will be present in the moist medium, but populations can be decreased greatly by drying to below 60% moisture content (v/v) (55).

Shrinkage away from the pot may be a problem since the fibrous celluloses and pentosans will have been broken down by the ruminant cattle. Non-ruminant waste (e.g. pig slurry) will still contain this fibre and be more resistant to shrinkage in the pot (101).

1985 Media

Available nutrients, physical and physico-chemical properties only determined.

Worm-Worked Pig Slurry (P or P85)

This medium will not be described in full again as most of the description given above for the 1984 batch also holds true for this sample. The main differences are in nutrient content. This batch contains less available calcium, magnesium and nitrogen than the 1984 batch, with a consequently lower conductivity (despite a higher potassium content).

Worm-Worked Cow Slurry (C or C85)

Nutrient content is the major difference between this and the 1984 batch. C85 has less available Ca and nitrogen, but more magnesium and phosphorus and much more potassium than C84. The conductivity of the 1985 sample is much higher than that of C84.

Doncaster Compost (D)

This compost contains high total levels of macronutrients, which are only moderately available. The availability of phosphorus is very low. Total levels of micronutrients and heavy metals are high, but they are relatively unavailable, with no Cd, Ni and Pb detectable in the water extract. The presence of a high total level of cadmium, however, would make this an inadvisable medium for the growth of food

crops.

The high pH at 7.03 will reduce the availability of phosphorus, magnesium and micronutrients with probable deficiencies resulting. Salinity problems are likely as the conductivity is quite high (index 7).

This compost will vary in nutrient content from batch to batch.

Practical Handling

The dry bulk density is very high which would make carrying difficult. This compost contains slivers of glass, pieces of plastic and scraps of rag, which may make handling unpleasant. It may also contain human pathogens which have survived the composting period or reinvaded following it (see Pereira-Neto et al (1986) for further details).

Water holding capacity is a little lower than that of sphagnum peat and the volume percent air a little higher.

This compost is similar to Lescost in many respects suggesting that municipal refuse/sewage sludge composts may not differ greatly from each other if produced in similar types of area (fairly industrial in this case). The town waste compost of Alt & Höfer (1986) (West Germany) also had similar properties with low availability of P and high soluble salt levels.

Pig Slurry Compost

This compost is high in all available macronutrients, and high in copper. It contains moderate levels of zinc. Other micronutrients were not measured, but are likely to be similar to those

in the worm-worked slurry (perhaps a little lower). High copper in both the pig slurry media is not surprising since this element is added to the diet of pigs.

The pH at 6.2 is a little high and the conductivity very high with probable salinity problems resulting.

The K:Mg ratio of 8:1 may lead to magnesium deficiency, although the available level of Mg is high. High phosphate is likely to give decreased iron availability as will the high pH, with possible deficiencies (Fe level probably similar to that of P).

Nutrient levels will vary from batch to batch.

Practical Handling

The dry bulk density is low and the water holding capacity and volume percent air similar to those of sphagnum peat. This medium tends to hold a lot of water when fresh from composting and requires drying out before use. The worm-worked pig slurry is finer and more even in particle size (because of sieving and breakdown by the worms). Unbroken down large lumps are present which make potting more difficult and handling less pleasant than for P.

CHAPTER 3

Growing Trials.

Tomato Trial.

F1 hybrid seed Cv. Shirley was sown, 200/seed tray on 31/5/84, and placed in a propagation house with bottom heat. The seedlings were pricked out into 9cm pots containing Levington Potting Compost and placed pot thick (temp. 18°C night, 30°C day) on 8/6/84 and spaced to 13cm centres on 21/6/84. On 27/6 they were again spaced to 25x20cm.

Bolster bags were filled with 21 litres of growth medium to give the following treatments:-

Code

F0	Medium alone.
F1	Medium with base dressing.
F2	Medium with base dressing and liquid feed.

For each of:-

	Code	
Lescost	Ls	
Spent Mushroom	M	
Cambark Fine	B	
Levington Potting	Lv	Total=
Leafmould	Lf	27 treatments
W.W. Pig Slurry	P	
W.W. Cow Slurry	C	
Sedge Peat	S	
Sphagnum Peat Control	SPC	

The weight of 396cm^3 of medium was measured using the Settling Equivalent method and multiplied up to give the weight of 21 litres. Bags were sealed with

staples at their mid point to give half length bags. The quantity of base dressing required for each medium was calculated using the medium analyses (table 2.6) to bring the nutrient levels up to those recommended for 100% sphagnum peat (12,15):-

PPM	ELEMENT	AS
175	Nitrogen	Ammonium nitrate
630	Potassium	Potassium sulphate
240	Phosphorus	Super phosphate
2770	Calcium	Ground limestone
360	Magnesium	Magnesium limestone
	Trace elements	Frit WM 255

Where a particular nutrient level already exceeded that recommended no further addition of that nutrient was made, and no attempt was made to reduce the level. The balance of nutrients was thus not the same for all the media but a minimum level of each was achieved. Leaching to reduce excessive nutrient levels would have interfered with other properties of the media such as pH and conductivity and was therefore not considered desirable.

The tomato plants were planted two per bag on 6/7/84 in a polythene tunnel 15.2m x 4.3m with a randomised block arrangement (fig.3.1), with 3 blocks and 27 bags per row. Each plant was supplied with a drip irrigation nozzle which gave 2 litres/plant/day, half at 9.00 am and half at 2.00pm. This was later reduced to 2/3 l/plant/day. Differential watering depending on growth rate was not possible. Drainage slits were cut in all modules. Liquid feeding of appropriate treatments commenced twice weekly 14 days after planting. The irrigation system was turned off

for one session on feeding days to prevent overwatering. Feed, double the strength recommended if given at every watering (15) (360:120:900 N:P205:K20), was dispensed from a watering can, and a quantity of liquid equal to that supplied by the irrigation system measured out in a beaker. This was poured onto the root ball of each plant. Plants not fed were given the same quantity of plain water. The same feeding rate was used for all plants irrespective of their growth rate. Feeding rate was increased to 500ml/plant at the end of August as control plants showed signs of nutrient deficiencies. Routine trimming, training and deleafing was carried out as necessary. Plants were stopped on the 22nd August and picking commenced on the 28th August. Fruit was picked twice weekly until the crop was cleared on the 27th September.

The following recordings were made:-

Plant Stature

Height of plant

From medium level to top leaf.

1. Initial height (to first truss).
2. Every two weeks to stopping.

Stem width

Taken half way up the plant (widest diameter) with a micrometer.

1. At end of cropping.

Analytical Samples

Leaf

Two leaves per plant (fully expanded) taken from the top of the plant.

1. Immediately before liquid feeding.
2. 5 weeks later.

Fruit

Two tomatoes taken from each plot (one/plant) on two dates (4/9 & 18/9, 8 & 22 days from start of harvest) for determination of heavy metal content with particular emphasis on the following:-

Medium	Element
Leafmould	cadmium, lead, nickel.
W.W Pig	cadmium, nickel, copper.
W.W.Cow	nickel.
Lescost	cadmium, lead, nickel.
Mushroom	cadmium.
Sphagnum peat control	cadmium, lead, nickel, copper.

Yield

1. As tomatoes ripened:- Number.
   Total weight.
   Grade (size and quality), according to EEC standards for fresh tomatoes (13).
2. Green tomatoes at the end of cropping:-
   Number.
   Total weight.

Leaf and fruit samples were treated as follows (44):-

Leaves - Washing: 1. 10% hydrochloric acid, 60 secs. changed every 8 samples.
2. Distilled water, 60 secs., changed every 4 samples.
3. Deionized water, 60 secs., changed every sample.

Drying: 4 hours at 102°C in a forced aeration oven.

Fruit - Washing: 1. 10% hydrochloric acid, 30 secs. changed every 6 samples.
2. Distilled water, 30 secs., changed every 3 samples.
3. Deionized water, 30 secs., changed every sample.

Drying: Tomatoes cut into small pieces and the juice plus the pieces put into 500ml kilner jars. Dried for 20 hours at 102°C in a forced aeration oven.

Dry leaves and fruit were stored in paper bags inside sealed polythene bags until analysed.

Block 1	Block 2	Block 3	
G	G	G	
SPCF1	LfF1	SPCFO	
PF1	SPCF2	LvF1	
LsF1	LsF1	LvFO	
SPCF2	MF2	LsF1	
SF2	SPCF1	LsF2	
MF1	CF2	PF2	
MFO	BFO	CFO	
CF2	SF2	LfF1	
CFO	MF1	BFO	
BF1	PFO	SF1	
LfF2	SFO	PF1	
PF2	BF1	CF1	
MF2	LfFO	SFO	N
LvFO	PF2	LfF2	<-------
SF1	LsF2	LvF2	
SFO	CF1	SF2	G=Guard
LfFO	PF1	PFO	
LsFO	LvF2	MF2	
LfF1	LvF1	CF2	
LvF1	CFO	LsFO	
BF2	LfF2	BF2	
BFO	LvFO	SPCF1	
CF1	SF1	SPCF2	
SPCFO	SPCFO	LfFO	
LvF2	MFO	BF1	
LsF2	LsFO	MFO	
PFO	BF2	MF1	
G	G	G	

Plan of Tomato Trial. Fig. 3.1

Tomato Trial Results and Discussion

Height of Plant

Figs.3.2a to 3.3c show the heights of plants with time to 47 days from planting (to when the plants were stopped). These are grouped according to initial conductivity of the media since this parameter gave the most natural grouping of the curves. Soluble salt content of the media appears to be the single most important factor in governing growth of tomatoes in all the media used. NB Scales are not all identical.

Low conductivity media

Media with initial low conductivity and nutrient content (Lf, B, S, and SPC) gave similar graphs (fig. 3.2a) with the biggest plants after 47 days on F2 treatments (base dressing + liquid feed), and the smallest on F0 (no added fertilizer). All these media supported growth equally for 7-12 days after planting, however, nutrition could have been supplied by the Levington Potting Compost used at the pricking out stage, and planted on with the root ball into the bag. The F0 treatment curves then begin to diverge from the F1 and F2 curves showing that low nutrition was limiting growth. After 30 to 35 days the F0 curves begin to flatten out indicating that no further vertical growth was possible and that the medium nutrients had effectively been totally depleted. The F1 curves follow a similar pattern, but diverge from the F2 curves at a later date and flatten out later than the F0 curves. The F2 curves show a more constant increase in size of the plants with no flattening out. Provided liquid feed was continued to be given the plants would theoretically

continue to increase in height.

High conductivity media :-

Lescost, worm-worked pig slurry and spent mushroom compost all had initial high conductivity and nutrient contents (see table 2.6). The graphs show that both M and Ls supported growth well without the addition of fertilizer. Liquid feed was apparently beneficial towards the latter end of the height measuring period only. Plants by this time would have used up a proportion of the available nutrients and some would have been leached away. Growth curves for plants in P were almost identical up to 47 days from planting irrespective of whether fertilizer was added or not. The use of these media could represent a considerable saving in fertilizer costs.

Intermediate conductivity media

LvP and C were of similar conductivity and nutrient contents initially and gave similar growth curves. It should be noted that the use of the term 'intermediate' is in fact for convenience since the recommended conductivity of tomato medium extracts at the start of cropping is 701-900 (index 5) and the term used should perhaps be 'optimal' (see Appendix 2).

A puzzling phenomenom seen with the intermediate and high conductivity media was that plants in F0 grew slightly taller than those in F1. An increase in salinity in the media from the addition of extra fertilizer to already saline media could be responsible for a depression in growth, but in this case plants in F2 would be expected to be depressed the most, as in this treatment the osmotic stress would be the greatest. This did not happen. A nutrient imbalance caused by the addition of the base

dressing to the media may have been responsible since no attempt was made to keep the ratio of nutrients equal, but instead a minimum level of nutrients was aimed for. Lime addition may have increased the pH from optimal. Liquid feed would have counteracted this slightly since it had the effect of lowering the pH of the irrigation water from 7.4 to 7.2.

Stem Width

Table 3.1 shows the mean stem diameter and mean plant height at stopping. These, and their product were correlated to mean yield of ripe fruit and to mean yield of ripe + green fruit. All were highly correlated to yield (P=0.001), stem diam.x height (dh) vs. ripe fruit yield being the most highly correlated. Equations and values of r^2(adj) were as follows:-

ripe fruit yield =(-1191 ±129) + (2139 ±94)stem diam.
r^2= 83.1% (d)

ripe fruit yield =(-2106 ±138) + (3.23 ±.115)height
r^2= 88.1% (h)

ripe fruit yield =(-347 ±54) + (0.125 ±.003)dh
r^2= 93.6%

ripe + green fruit yield =
(-3719 ±503) + (5006 ±367)d
r^2= 63.7%

ripe + green fruit yield =
(-6226 ±545) + (7.87 ±.46)h
r^2= 73.6%

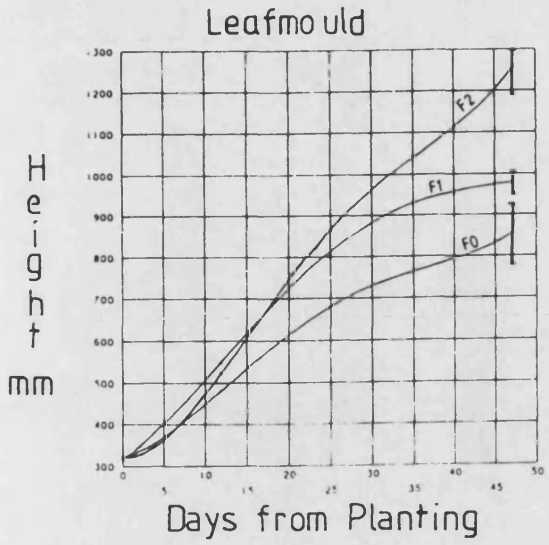
ripe + green fruit yield =

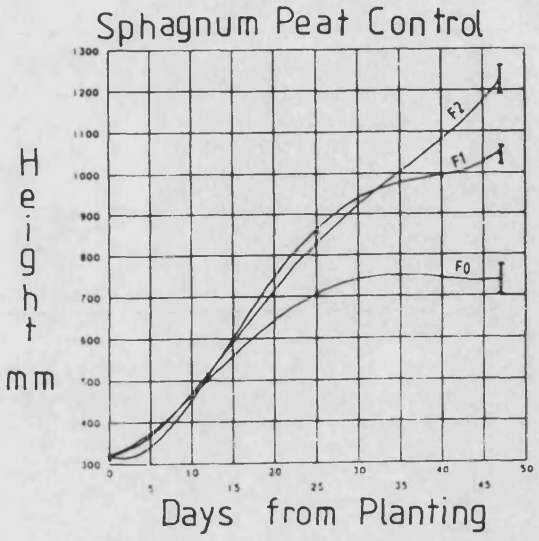
$$(-2046 \pm 245) + (.31 \pm .014)dh$$

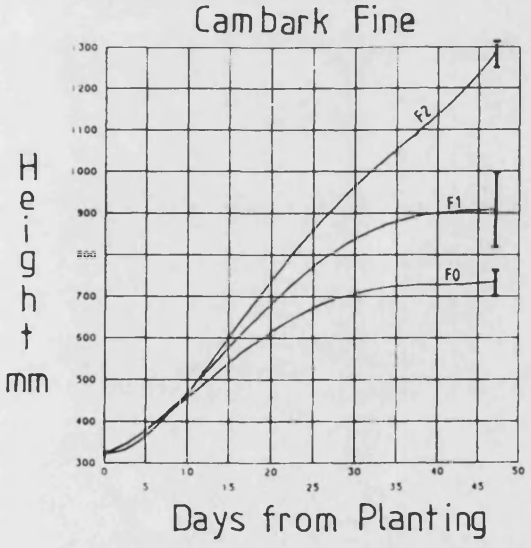
$r = 81.8\%$

Degrees of freedom = 25

Fig.3.4 shows the relationship between stem diam. x plant height and yield of ripe fruit. If this were found to be a reliable relationship in repeated experiments, the simple measurement of stem diameter or plant height or both could be used to predict yields rather than the more time consuming process of picking and weighing the fruit.







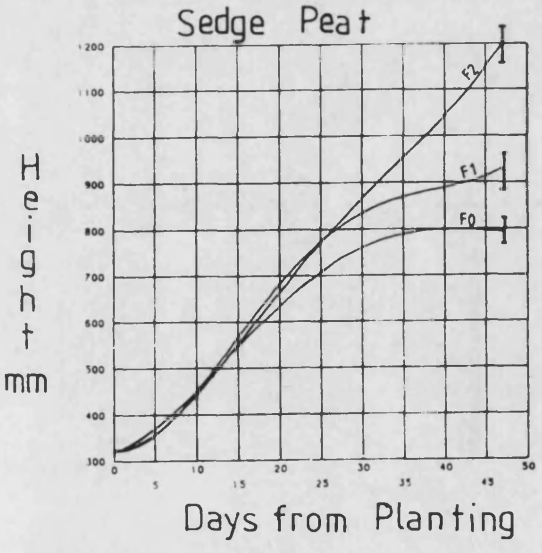
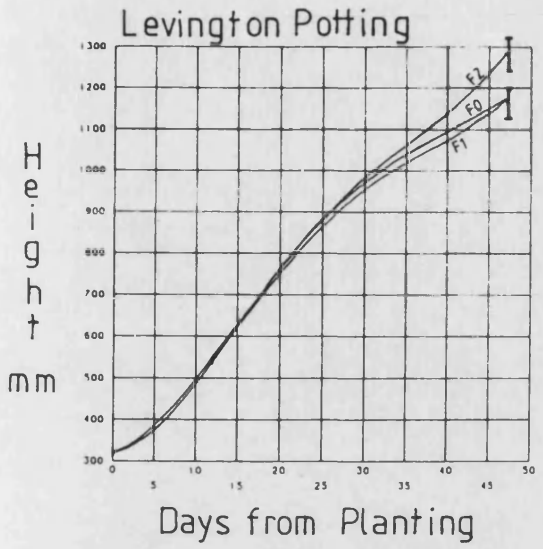
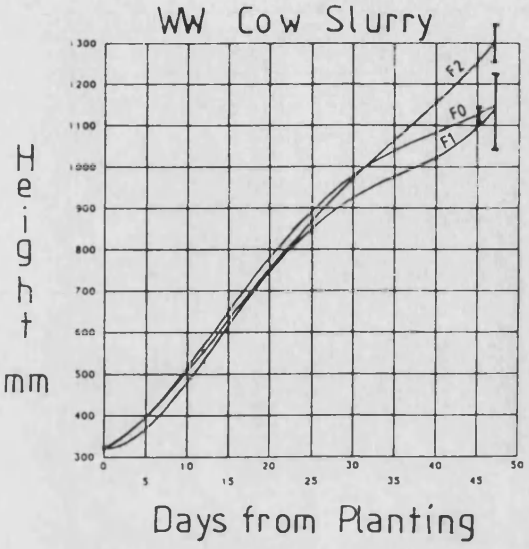


Fig. 3.2a Plant Height with Time - Low Conductivity Media.





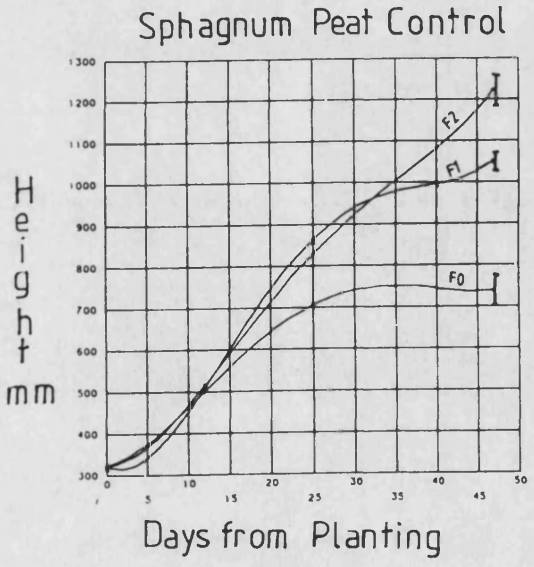
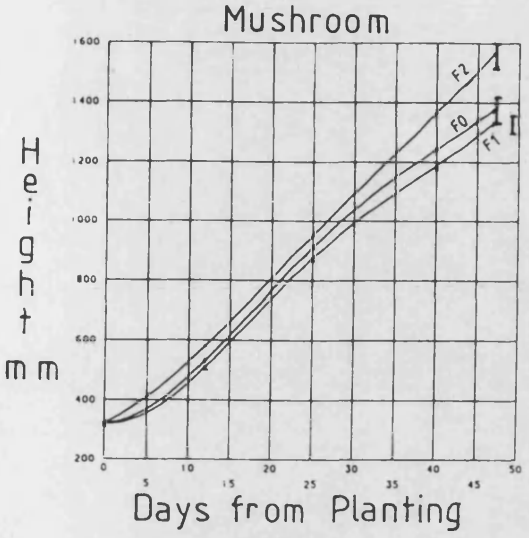
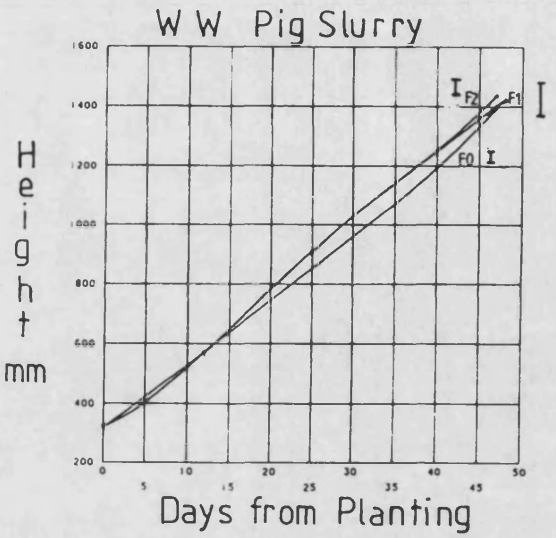
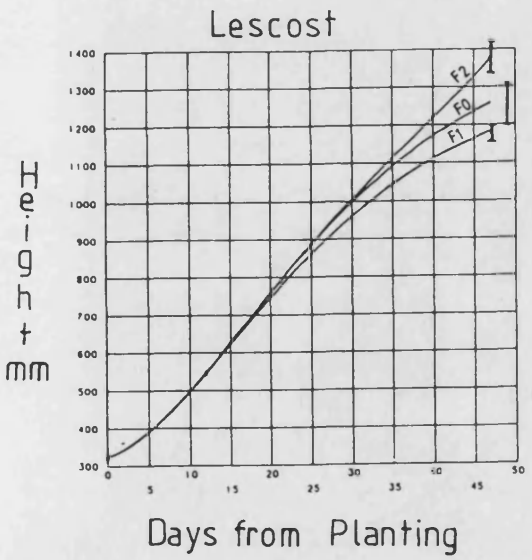


Fig. 3.2b Plant Height with Time - Intermediate Conductivity Media (with Sphagnum Peat for Comparison).







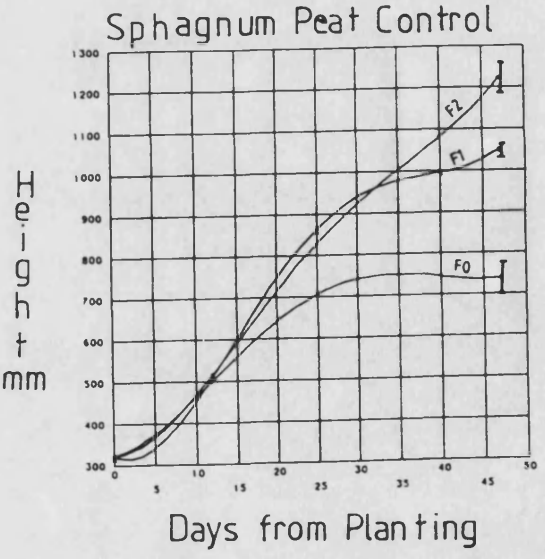


Fig. 3.2c Plant Height with Time - High Conductivity Media (with Sphagnum Peat for Comparison).

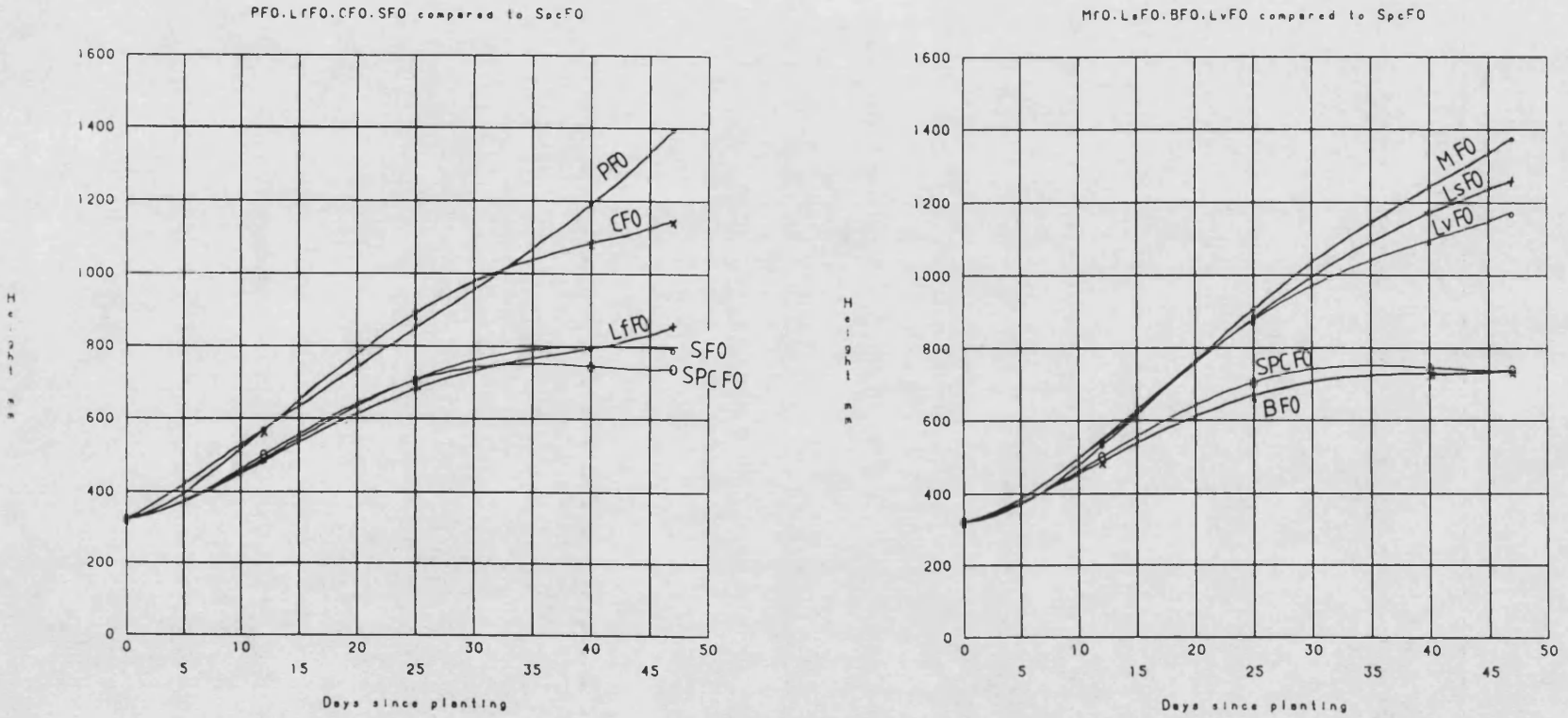


Fig. 3.3a Plant Height with Time - Comparison of Media - Treatment FO.

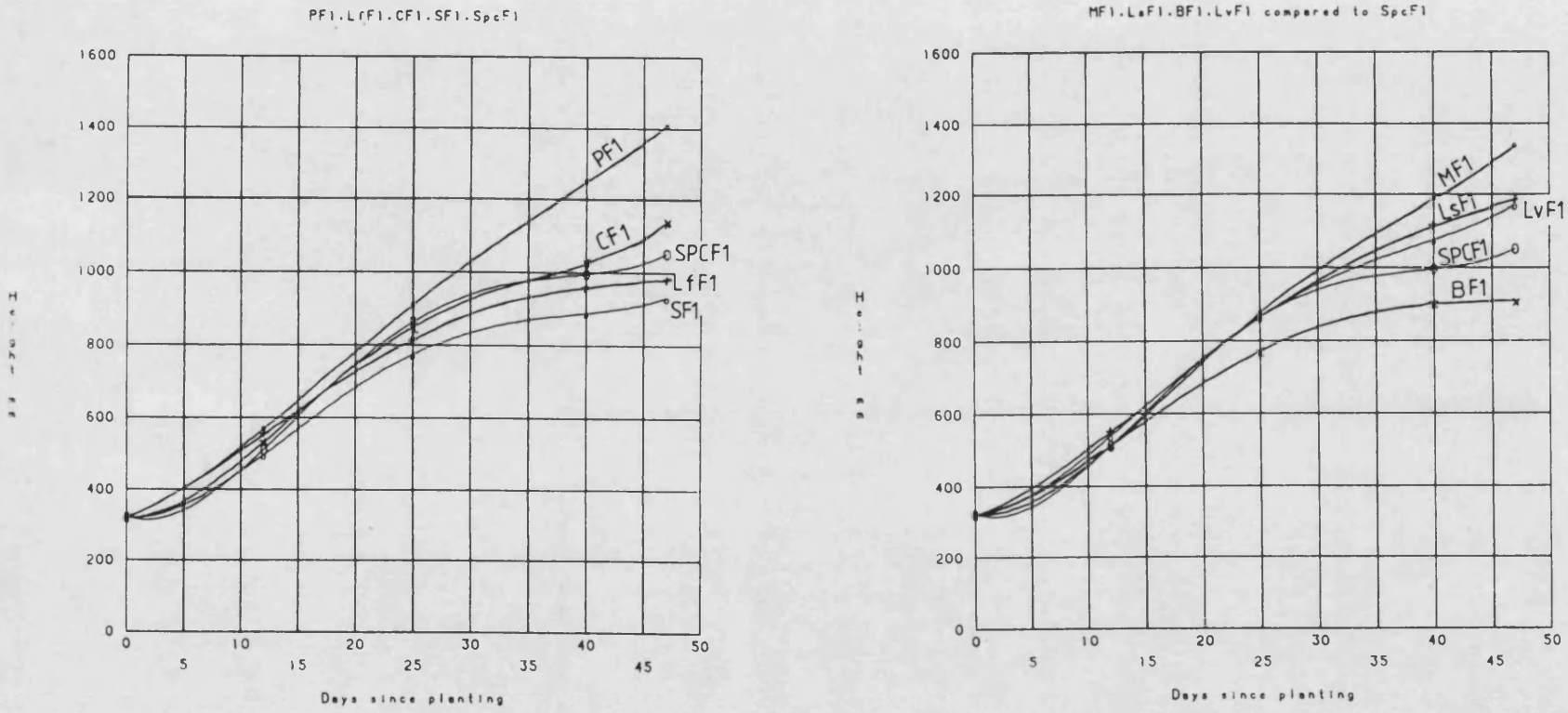


Fig. 3.3b Plant Height with Time - Comparison of Media - Treatment F1.

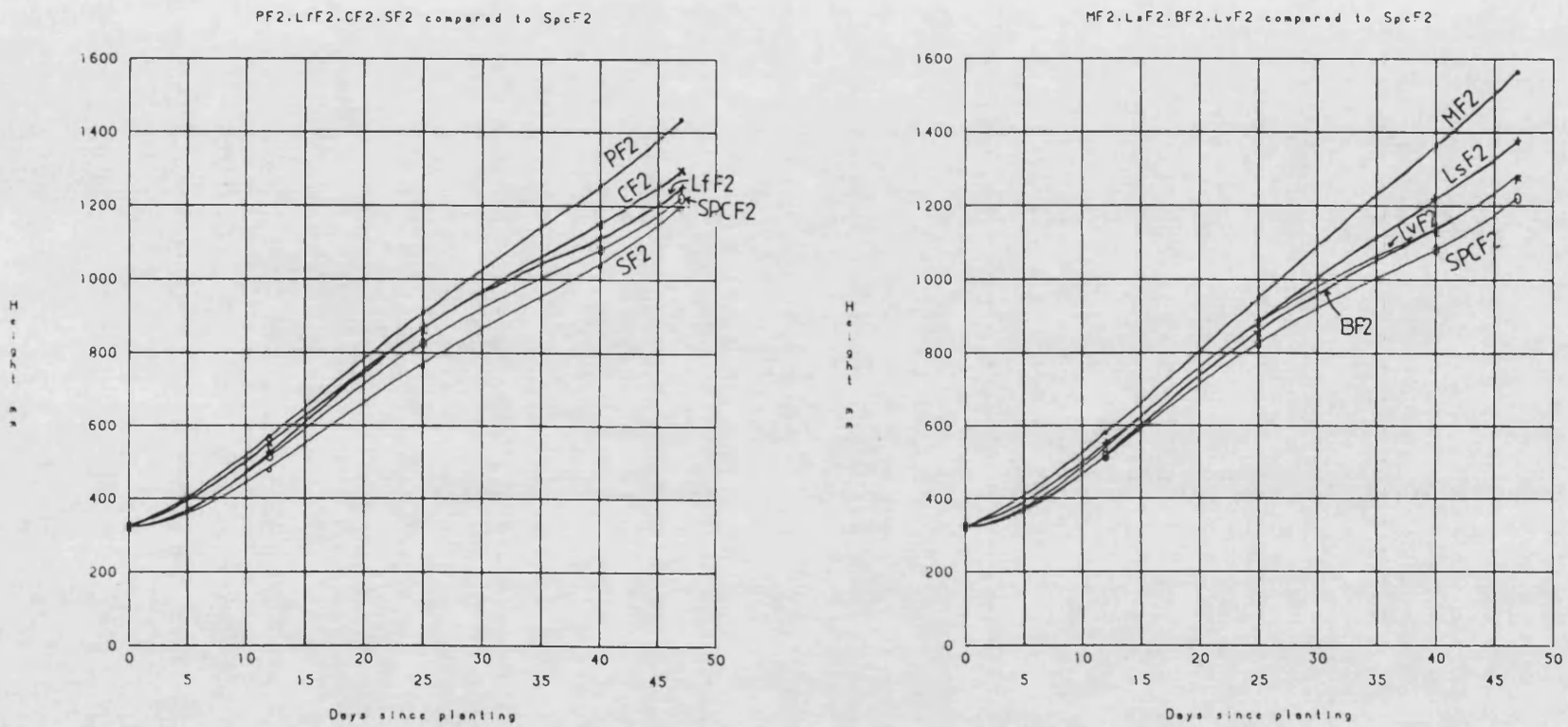


Fig. 3.3c Plant Height with Time - Comparison of Media - Treatment F2.

TREATMENT	MEAN STEM DIAM. (cm)	MEAN PLANT Ht. AT STOPPING (cm)	PLANT Ht. X STEM DIAM. $(cm)^2$	MEAN YIELD RIPE FRUIT (g)	MEAN YIELD RIPE + GREEN FRUIT (Kg)
LsF0	1.38	125.7	173.47	1786	2.513
LsF1	1.49	118.3	176.27	1749	2.280
LsF0	1.56	137.3	214.19	1920	3.913
MF0	1.35	137.3	185.36	2161	3.497
MF1	1.37	133.7	183.17	2084	3.207
MF2	1.41	156.2	220.24	2747	5.287
BF0	0.70	73.3	51.31	265	0.300
BF1	1.01	90.8	91.71	585	0.693
BF2	1.18	128.3	151.39	1532	2.573
LvF0	1.43	117.3	167.74	1908	2.403
LvF1	1.58	117.0	184.86	1961	2.483
LvF2	1.60	128.2	205.12	2416	4.513
LfF0	0.68	85.3	58.00	440	0.577
LfF1	1.16	98.0	113.68	876	1.013
LfF2	1.43	124.8	178.46	1724	2.940
PF0	1.64	139.2	228.29	2374	7.013
PF1	1.78	140.7	250.45	2869	6.313
PF2	1.78	143.5	255.43	2375	8.003
CF0	1.68	114.5	192.36	2135	2.900
CF1	1.57	113.8	178.67	1947	2.617
CF2	1.68	129.8	218.06	2316	4.760
SF0	0.82	79.2	64.94	385	0.467
SF1	1.23	93.0	114.39	923	1.123
SF2	1.26	119.8	150.95	1768	2.967
SPCF0	0.65	73.5	47.78	291	0.350
SPCF1	1.13	105.0	118.65	1167	1.313
SPCF2	1.40	122.0	170.80	2038	3.530

TOMATO YIELD, STEM DIAMETER AND PLANT HEIGHT TABLE 3.1

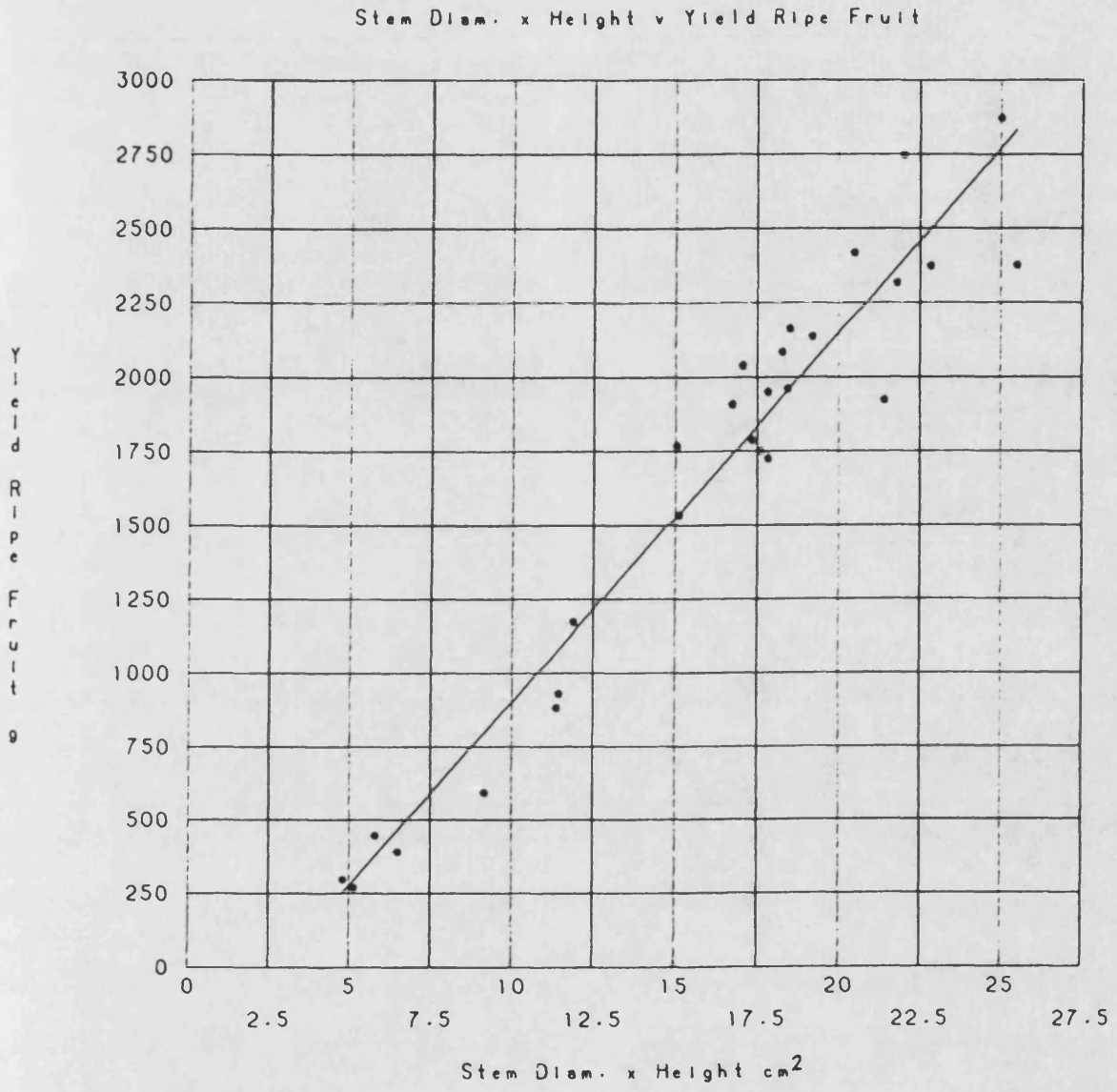


Fig. 3.4 Tomato Stem Diameter x Height vs. Yield of Ripe Fruit.

Yield

Table 3.1 shows the mean yield of ripe fruit and ripe + green fruit per plot. Figs.3.5a to 5.3c show the cumulative mean yields of ripe fruit from the start of harvest (day 52 from planting = day 0 of the harvest period) to day 83 (day 31 of the harvest period), when all fruit were cleared. Fig. 3.6 shows graphically the total yield of ripe and ripe + green fruit with treatment (with standard errors indicated). Analyses of variance were carried out as can be seen in fig 3.7 and the following summary.

Ripe Fruit

PF1 and MF2 produced significantly greater yields of ripe fruit than the control SPCF2 (P=0.001). BF0, SPCF0, SF0, LfF0, BF1, LfF1, SF1, and SPCF1 produced significantly lower yields than the control (P=0.001) as did BF2 (P=0.05). All other treatments were not significantly different from SPCF2.

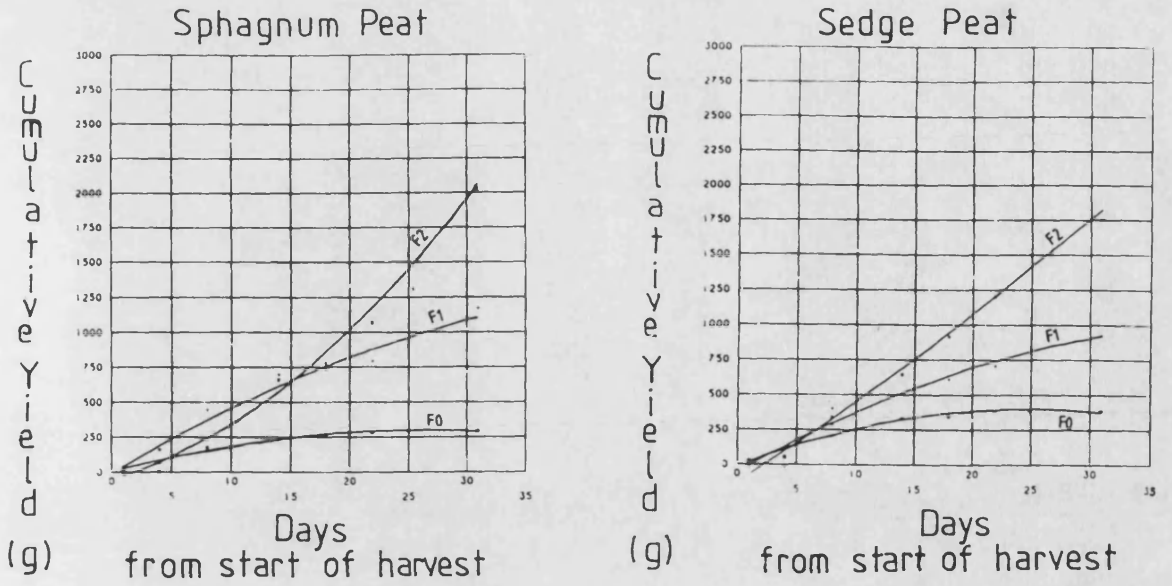
The results of the overall effects of medium and fertilizer treatments can be seen in the summary. P, M, C, Lv (P=0.001) and Ls (P=0.01) all gave significantly greater yields overall than the control, whilst SPC, S, Lf and B were not significantly different. F2 gave a significantly better overall yield than F1 (P=0.01) and F0 (P=0.001) which were not significantly different.

Ripe + Green Fruit

PF2,PF1,PF0,MF2 (P=0.001), CF2 (P=0.01), and LvF2 (P=0.05) all gave significantly greater total yields than SPCF2.

BF0,BF1,SPCF0,SPCF1,LfF0,LfF1,SF0,SF1 (P=0.001), LsF0,LsF1,LvF1 (P=0.01), BF2 and CF1 (P=0.05) all gave significantly lower total yields than SPCF2.

The medium and fertilizer effect ANOVAs gave similar results to those for ripe fruit, except that P was significantly greater for total yield than all the other treatments (P=0.001).



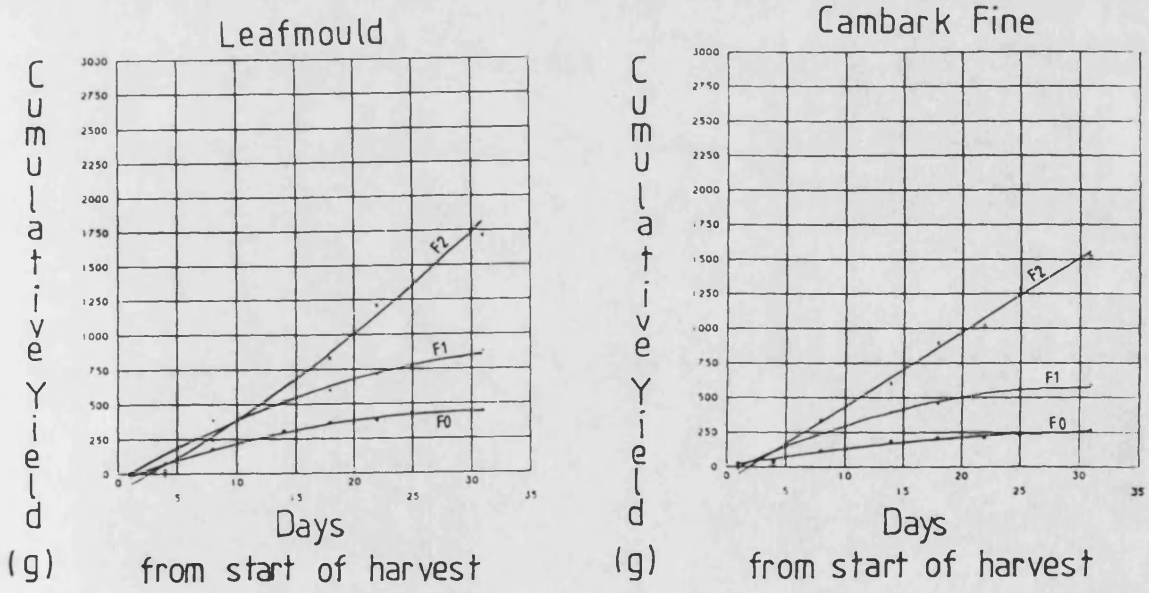


Fig. 3.5a Cumulative Mean Yield with Time - Low Conductivity Media.

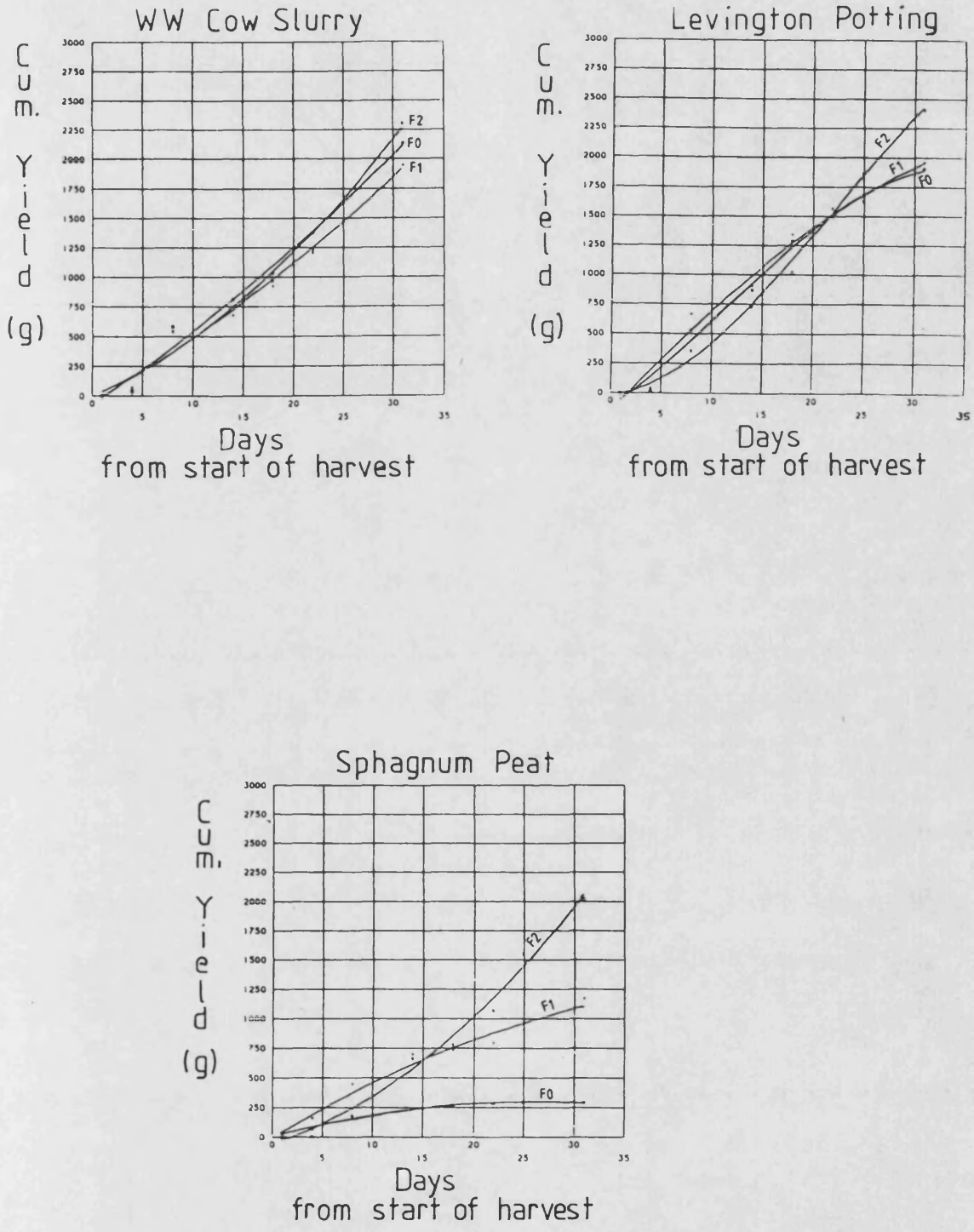
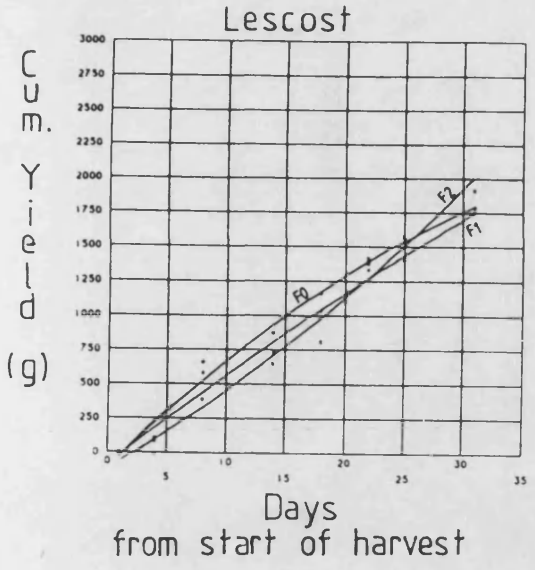
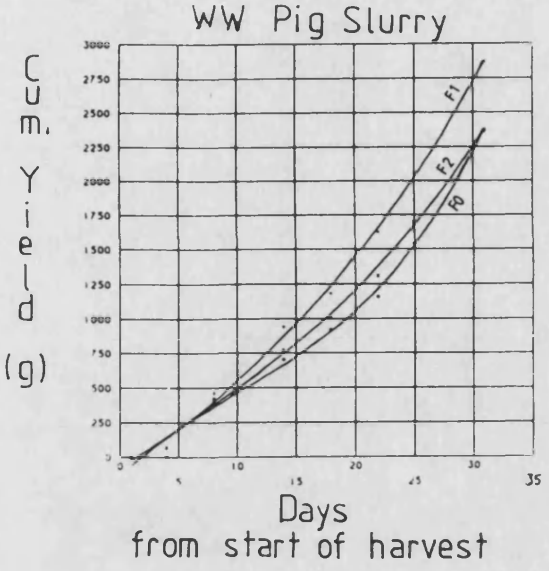
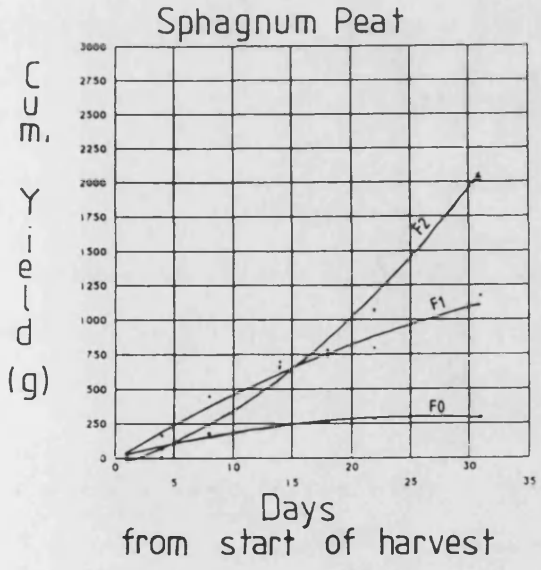


Fig. 3.5b Cumulative Mean Yield with Time - Intermediate Conductivity Media (with Sphagnum Peat for Comparison).







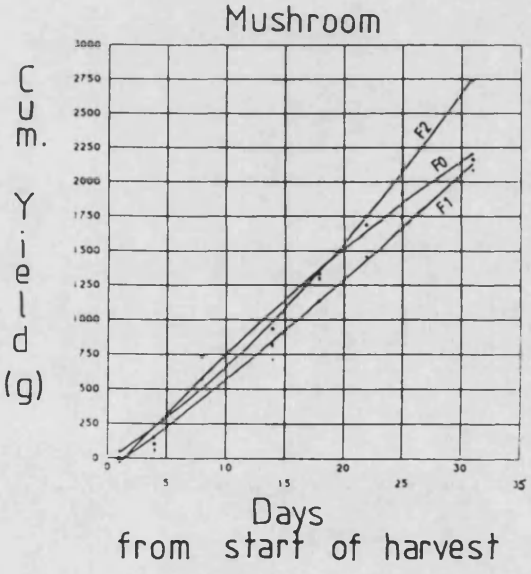


Fig. 3.5c Cumulative Mean Yield with Time - High Conductivity Media (with Sphagnum Peat for Comparison).

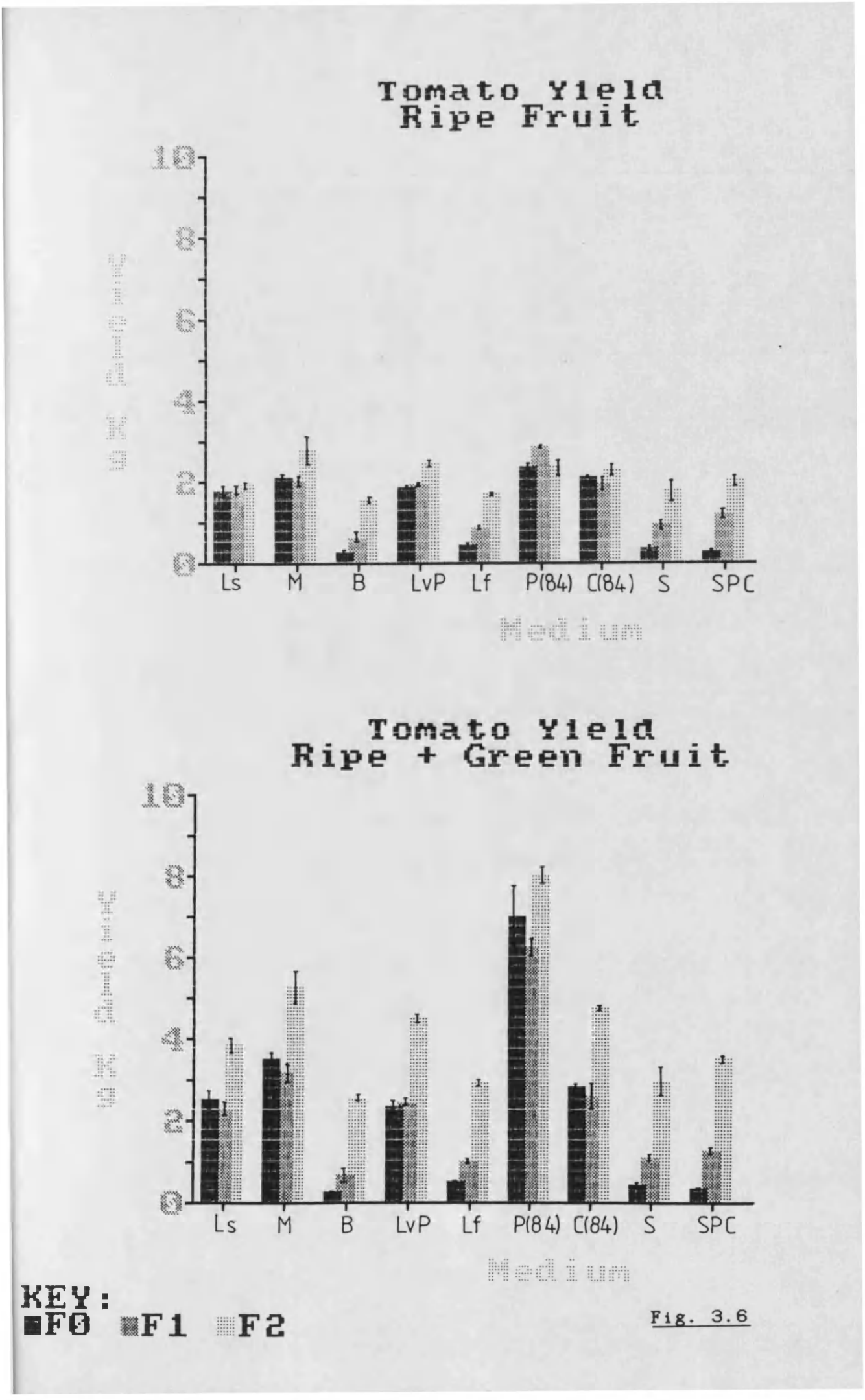
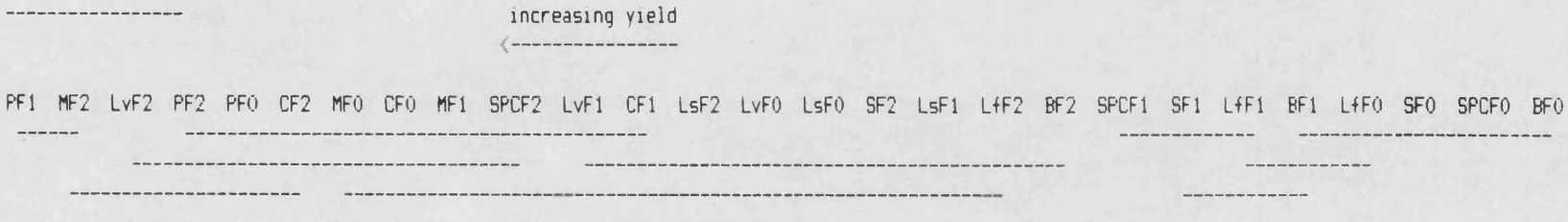

Tomato Yield
Ripe Fruit
10
8
6
4
2
0
Ls
M
B
LvP
Lf
P(84)
C(84)
S
SPC
Medium
Tomato Yield
Ripe + Green Fruit
10
8
6
4
2
0
Ls
M
B
LvP
Lf
P(84)
C(84)
S
SPC
Medium
KEY:
F0
F1
F2

Fig. 3.6

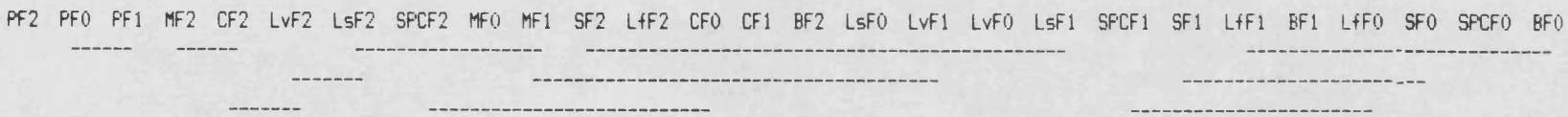
RIPE FRUIT / PLOT

increasing yield



RIPE + GREEN FRUIT / PLOT

increasing yield



TOMATO YIELD ANOVA RESULTS FIG. 3.7

Tomato Yield ANOVA Results. (Summary).

Ripe Fruit

	Treatment Effect	Medium Effect	Fertilizer Effect
Df	54	72	78
LSD 0.05	458	482	397
LSD 0.01	612	641	520
LSD 0.001	805	834	687
f-ratio	22.99***	15.03***	8.23***
n	3	9	27

See fig.3.7 for Treatment Effect ANOVA diagram.

Medium Effect

increasing yield (g)

<----------

2545	2331	2138	2095	1818	1166	1025	1013	794
P	M	C	Lv	Ls	SPC	S	Lf	B

Fertilizer Effect

increasing yield (g)

<----------

2096	1574	1305
F2	F1	F0

Ripe + Green Fruit

	Treatment Effect	Medium Effect	Fertilizer Effect
Df	54	72	78
LSD 0.05	0.77	0.73	0.71
LSD 0.01	1.03	0.98	0.95
LSD 0.001	1.35	1.27	1.23
f-ratio	57.46***	25.21***	9.55***
n	3	9	27

See fig.3.7 for Treatment Effect diagram.

Medium Effect

increasing yield (Kg)

<----------

7.11	4.00	3.43	3.13	2.90	1.73	1.52	1.51	1.19
P	M	C	Lv	Ls	SPC	S	Lf	B

Fertilizer Effect

increasing yield (Kg)

<----------

4.28	2.34	2.22
F2	F1	F0

Fruit Grade

Table 3.2 shows the percentage of fruit in the three grades. Most fruit were of grade 1 except for those from the worm-worked pig slurry treatments, which frequntly had large cracks around the calyx. Trusses on P treatments were so laden with fruit that they tended to break from the plant. Plants in P may have been growing so quickly, and transpiring so rapidly that the medium dried out between waterings thus giving extreme fluctuations in medium moisture content. This is known to cause fruit splitting (12).

Analytical Samples

Table 3.3 shows the heavy metal content of tomatoes and table 3.4 the leaf nutrient contents.

Heavy Metals in Fruit

Cadmium

This was detectable only in Lescost grown fruit. Cd is zootoxic at levels >0.5 mg/kg dm (Davis (1979)), however any medium giving a detectable level of this element in food crops should be avoided as Cd is a cumulative poison. Concentrations of Cd in both samples (from 4/9 and 18/9/84) were towards the upper limit of normal levels found in plant materials (0.01-0.3 mg/kg dm, Allen (1974)) and actually exceeded the upper limit in one replicate.

Nickel

Normal levels in plant materials are 0.5-5 mg/kg dm (Allen (1974)). Very little Ni was found in the 4/9 samples, but levels had increased quite considerably by 18/9 for Lf, C and Ls, being several

times the maximum normal level of 5mg/kg dm in some samples. Stentiford et al (1985) found <1mg/kg dm in their refuse compost (D in this study) and a commercial medium. Ni is principally phytotoxic (Davis (1979)), rather than zootoxic.

Copper

Normal levels in plant materials are 2.5-25 mg/kg dm (Allen (1974)). Stentiford et al (1985) found 12 mg/kg dm in D and a commercial medium. Levels found here were all within these normal levels, even for P which had very high total and available levels of Cu.

Lead

No Pb was detectable in any of the fruit.

Conclusion

The use of Lescost and media containing similar levels of cadmium (e.g. Doncaster compost (D)), for food crops would be inadvisable. Davis (1979) stated that Cd concentrations in plant parts decrease in the order fibrous roots> leaves> seeds = storage organs. Leafy crops would therefore accumulate even more of the metal than the fruit measured here. Approximately 12Kg of fresh tomatoes containing the levels of Cd measured here would have to be eaten in one week to exceed the tolerable weekly intake of 0.4-0.5mg (46), however, concentrated in the form of puree or sauce this would not be impossible.

Leaf Nutrients

Levels of nutrients in leaves were lower 47 days from planting (22/8) than at 13 days (19/7). The liquid feed rate was evidently too low to maintain nutrient levels in the media. The rate was increased when it became evident from visible symptoms that

Treatment	Grade 1	Grade 2	Grade 3
LsF0	92.6	1.3	6.1
LsF1	97.5	0.0	2.5
LsF2	89.4	1.0	9.6
MF0	99.0	0.0	1.0
MF1	97.0	1.1	2.0
MF2	96.8	2.5	0.6
BF0	83.6	6.7	9.7
BF1	92.6	0.0	7.4
BF2	98.7	0.0	1.3
LvF0	92.6	0.0	7.4
LvF1	91.5	2.2	6.2
LvF2	96.6	2.3	1.1
LfF0	94.4	5.6	0.0
LfF1	98.2	0.0	1.8
LfF2	96.0	1.4	2.6
PF0	62.3	34.5	2.2
PF1	85.5	10.1	4.4
PF2	57.4	32.8	9.8
CF0	98.8	0.0	1.2
CF1	96.8	2.0	1.1
CF2	89.0	7.1	3.9
SF0	100.0	0.0	0.0
SF1	98.3	0.0	1.7
SF2	97.8	1.1	1.1
SPCF0	82.1	4.2	13.7
SPCF1	97.2	0.0	2.8
SPCF2	98.7	1.3	0.0

PERCENTAGE OF TOMATO FRUIT IN GRADES 1 - 3 Table 3.2

		Cadmium		Nickel		Copper		Lead	
		4/9	18/9	4/9	18/9	4/9	18/9	4/9	18/9
Leafmould	F0	0	0	1.3	16.0	1.75	2.83	0	0
	F1	0	0	0	22.0	1.50	4.25	0	0
	F2	0	0	0	7.0	4.00	1.00	0	0
WW Cow	F0	-	-	0	0.0	5.50	7.25	0	0
Slurry	F1	-	-	1	9.3	2.00	5.58	0	0
	F2	-	-	0	0.0	8.50	6.25	0	0
Lescost	F0	0.350	0.275	0	2.7	4.00	5.50	0	0
	F1	0.250	0.175	0	17.0	4.50	3.33	0	0
	F2	0.225	0.175	0	3.0	3.00	4.00	0	0
WW Pig	F0	0	0	0	0.0	2.50	7.83	0	0
Slurry	F1	0	0	0	0.0	5.50	7.33	0	0
	F2	0	0	0	0.0	9.00	7.42	0	0
Mushroom	F0	0	0	-	-	3.75	5.25	0	0
	F1	0	0	-	-	1.50	3.42	0	0
	F2	0	0	-	-	7.00	2.67	0	0
Sphagnum	F0	0	0	0	0.0	2.00	2.67	0	0
Peat	F1	0	0	0	0.0	3.25	2.43	0	0
	F2	0	0	0	0.0	3.00	3.33	0	0

Tomato Fruit Heavy Metal Content (mg/Kg dm) Table 3.3

Treatment		K mg/g dm		Mg mg/g dm		P mg/g dm		Fe ppm dm		Cu ppm dm		Zn ppm dm	
		19/7	22/8	19/7	22/8	19/7	22/8	19/7	22/8	19/7	22/8	19/7	22/8
Lescost	F0	41.63	24.46	4.38	2.24	4.27	1.19	107	46	21.4	9.9	116.7	57.9
	F1	39.04	20.83	4.22	2.11	6.27	1.79	112	41	21.2	6.1	105.9	35.4
	F2	38.96	28.13	4.24	2.35	5.82	2.28	106	38	20.4	8.5	93.6	29.2
Mushroom	F0	45.96	35.15	3.87	3.13	5.98	3.03	84	48	15.2	7.7	114.2	48.8
	F1	42.34	29.73	3.88	2.69	6.10	2.74	91	39	17.6	7.3	97.7	38.6
	F2	45.25	39.09	4.14	3.06	6.02	3.53	83	44	17.1	10.2	95.5	41.0
Cambark	F0	15.00	10.15	2.71	3.01	2.96	2.43	44	27	4.8	2.2	21.1	15.6
Fine	F1	30.50	13.29	3.16	2.49	5.41	2.35	68	24	10.7	2.0	53.0	18.7
	F2	36.75	20.17	3.47	2.33	6.67	2.06	85	29	13.1	2.7	66.1	25.3
Levington	F0	32.08	14.38	3.82	2.53	8.16	2.23	134	41	21.9	3.6	87.3	15.5
Potting	F1	32.96	17.98	4.38	2.36	7.36	2.16	110	43	19.4	4.4	91.8	18.0
	F2	34.42	28.06	4.01	2.82	7.78	2.22	115	42	20.1	5.7	93.4	22.3
Leafmould	F0	15.33	13.44	2.59	3.80	2.85	3.17	49	31	4.6	5.1	18.1	24.3
	F1	33.42	14.77	3.44	2.27	6.35	2.39	100	30	15.5	2.6	54.2	16.7
	F2	34.67	20.64	3.90	2.18	6.17	2.35	99	32	15.3	3.1	61.2	13.5
WW Pig	F0	37.42	33.50	6.45	4.24	6.06	3.98	89	61	20.5	15.0	116.7	37.5
Slurry	F1	35.75	34.82	6.71	4.14	6.23	3.67	94	58	23.6	16.0	107.1	26.7
	F2	36.42	35.96	6.33	4.27	6.03	4.20	97	64	22.8	16.8	107.5	35.3
WW Cow	F0	35.67	18.98	4.44	2.31	6.45	2.76	100	34	22.3	11.9	150.9	46.0
Slurry	F1	31.84	18.48	5.17	2.40	6.57	2.68	92	32	22.5	10.3	139.6	32.9
	F2	36.75	25.58	5.19	2.55	6.58	2.90	94	34	23.3	11.1	145.5	38.6
Sedge	F0	14.04	5.91	3.23	3.28	2.49	0.95	96	47	4.6	1.5	21.5	12.0
Peat	F1	29.79	13.77	3.52	1.97	5.96	2.27	102	32	6.9	1.9	52.5	15.6
	F2	27.13	19.19	3.71	2.54	5.61	2.25	112	33	6.9	2.7	47.5	14.8
Sphagnum	F0	8.80	2.72	3.10	5.43	2.15	1.14	50	38	4.2	2.1	11.7	11.8
Peat	F1	36.25	16.36	4.18	3.11	6.87	1.75	118	35	11.8	2.8	80.8	24.3
Control	F2	38.75	25.27	4.15	3.40	7.72	1.81	109	49	13.4	4.0	101.7	21.7

Tomato Leaf Analyses Table 3.4

SPCF2 was becoming deficient.

Potassium :- High potassium levels are required for a tomato crop, much higher than for any other horticultural crop. The high K is required to ensure good fruit quality as well as vegetative growth. The typical level of K for tomato leaves is 5.5% dm (12). All the treatments had lower K levels than this, SPCFO and SFO being undoubtably deficient (≤0.9%, Peterson (1982)(109)).

At 13 days (before liquid feeding began) the levels of leaf K in F1 and F2 treatments were similar as expected, but by 47 days the effect of the feed can be clearly seen for all the treatments except P, for which FO and F1 had similar levels of leaf K to F2.

Phosphorus :- Typical content 0.5% dm (12)
Deficiency ≤0.15% dm (109)

None of the treatments were apparently deficient of phosphorus at 13 days, although BFO, LfFO, SFO, and SPCFO were well below the typical level. By 47 days all but the P treatments were on the low side, with LsFO, SFO, and SPCFO deficient. Differences between liquid fed and unfed treatments at 47 days were not obvious for phosphorus.

Magnesium :- Typical level 0.5% dm (12)
Deficiency ≤0.15% dm (109)

None of the treatments had levels of Mg below that quoted as deficient, however, only the P and C treatments had greater than the typical level of Mg at 13 days, and all had less after 47 days, excepting SPCFO. Mg was not supplied in the liquid feed, so no differences could be expected between F1 and F2 treatments for Mg levels.

Iron :- Typical level 90 mg/kg dm (12)

Deficiency ⩽50 mg/kg dm (109)

BFO, LfFO, and SPCFO were all deficient by 13 days from planting, but by 47 days only P treatments were not deficient. Iron deficiency can readily occur in tomato crops in soilless substrates in mid-season when laden with fruit. High medium pH can also induce Fe deficiency as in M, Ls, and Lf. Differences between fertilized (F1, F2) and unfertilized (FO) treatments were not obvious.

Copper :- Typical level 15 mg/Kg dm (12)

Deficiency <5 mg/Kg dm (12)

Toxicity ⩾25 mg/Kg dm (109)

Several treatments had greater than the typical level of leaf Cu at 13 days, though none were above the toxic level. BFO, LfFO, SFO, and SPCFO were already deficient by 13 days. Several more treatments were deficient by 47 days including SPCF2 and LvF1.

Zinc :- Typical level 80 mg/Kg dm (12)

Deficiency ⩽14 mg/Kg dm (109)

BFO, LfFO and SFO were all particularly low in Zn at 13 days, and SPCFO was deficient. All the other treatments had sufficient Zn. C treatments had by far the heighest leaf Zn levels at 13 days despite having less total and available medium Zn than P, M and Ls. This may be explained by the fact that Zn availability is reduced at high pH and also by high levels of phosphorus in the medium (Bunt(1976)). After 47 days most of the treatments were low in Zn, those with high reserves being evident from comparison with SPCF2.

No obvious reason for FO treatments producing larger plants and higher yields than F1 treatments on some of the higher conductivity media can be seen from the leaf nutrient levels.

Overall Comparison of Media

Little benefit is gained from base dressing addition without liquid feed for any of the media. High soluble salt containing media such as M, P and Ls may actually perform better if liquid feed but no base dressing is added. F1 treatments for the medium and high conductivity media actually produced smaller plants and lower yields than the FO treatments. The inclusion of a 4th treatment where liquid feed but no base dressing were added would have been useful.

P produced by far the greatest total yield of ripe + green fruit, but the quality of ripe fruit was reduced by splitting around the calyx and breaking of trusses under the weight of the fruit. The plants in P were very vigorous and bushy and created excessive shading of the fruit. Plants in M in comparison were far more typical of commercially grown plants in shape, with minimal shading of the fruit (see photographs 3.1 and 3.2). C produced good quality fruit and CF2 produced a significantly higher total yield than the control. LsF2 was not significantly different from the control in terms of yield, and the fruit were of excellent quality, being perfect in shape and colour. It is particularly unfortunate, therefore, that this medium contained such high levels of Cd.

Photo. 3.1 Worm-Worked Pig Slurry. Large Bushy Plants with Excessive Shading of Fruit.

Photo. 3.2 Spent Mushroom Compost. More Normal Shaped Plants with Little Shading of Fruit.

Evaluation of Analytical Techniques

Leaf and medium nutrient levels were correlated to yield (ripe fruit) using simple and multiple correlation techniques. Best fit curves were also fitted using a polynomial curve fitting program; Curplot (162). Although the results of the correlations are interesting in their own right in indicating relationships between soil and plant, they really serve here to show the success or otherwise of the different analytical techniques and growth measurement methods used. This will be discussed further later. Great statistical detail of results is therefore avoided here, but can be obtained from the author if required.

The following results were found:-

Leaf Nutrients (x) vs Yield Ripe Fruit (y)

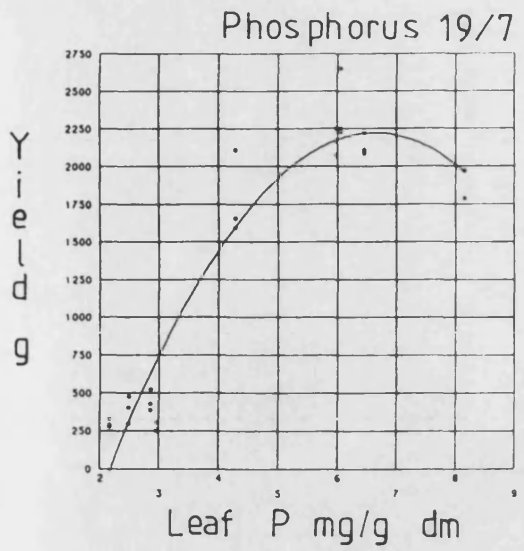
Nutrient	Leaf Harvest Date	r^2	Significance Level	
P	19/7	75.1%	***	
P	22/8	20.1%	*	
K	19/7	86.9%	***	
K	22/8	69.0%	***	n=27
Mg	19/7	63.5%	***	df=25
Mg	22/8	14.1%	*	
Fe	19/7	44.4%	***	
Fe	22/8	30.8%	**	
Cu	19/7	86.5%	***	
Cu	22/8	63.8%	***	
Zn	19/7	89.5%	***	
Zn	22/8	51.0%	***	

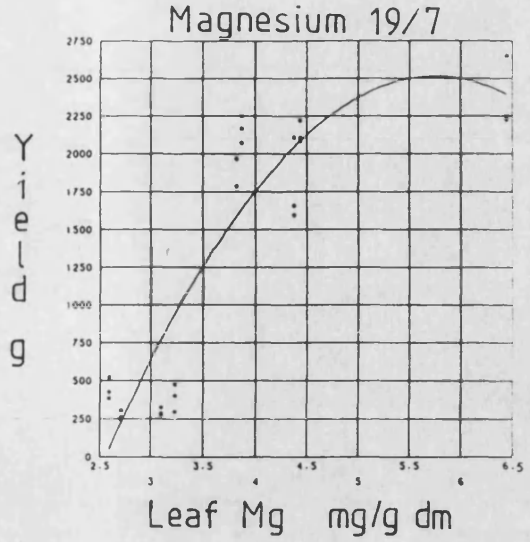
Verlodt et al (1985) also found good correlations between leaf Fe, leaf Cu and yield, but found negative correlations between phosphorus and potassium leaf levels after one month and yield. All the above correlations were positive.

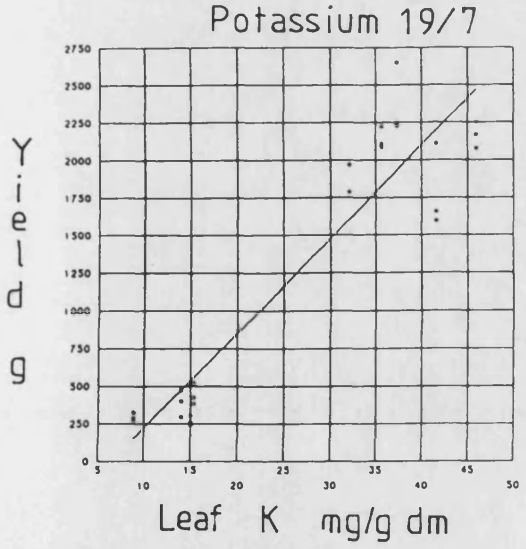
The curve fitting program (curplot) gave quadratic relationships as the best fit for leaf copper, iron, magnesium, zinc and phosphorus vs. yield and a linear relationship for potassium.* Representative curves can be seen in fig.3.8. These graphs show that despite the statistical significance of the correlations the scatter of the points is quite high. Also insufficient mid-range points are present to be sure of the calculated relationships.

The leaf samples were taken on 19/7 and 22/8 (13 and 47 days from planting), whilst harvest of fruit did not commence until 53 days from planting and ended on the 83rd day. This suggests that leaf analysis may give an indication of the expected yield even before the first fruit ripen.

* NB All the treatments had low levels of leaf K which may account for the relationship being linear rather than quadratic.







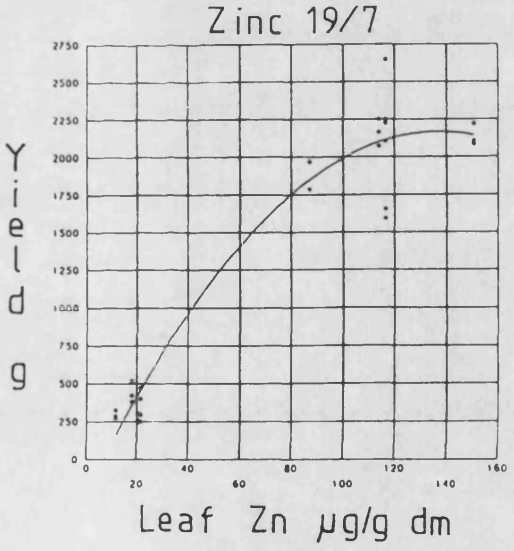


Fig. 3.8 Relationship Between Leaf Nutrient Levels and Tomato Yield.

Available Nutrients (x) vs Yield Ripe Fruit (y)

FO treatments only included in these correlations.

Nutrient	r^2	Significance Level	df
P	40.6%	***	25
K	44.1%	***	25
Mg	44.8%	***	25
N	73.3%	***	25
Ca	53.4%	***	25
N+Ca	85.9%	***	24
P+K	70.5%	***	24
N+K	88.1%	***	24
N+K+Ca	89.9%	***	23
N+K+Mg	87.7%	***	23
N+K+P	87.7%	***	23
P+K+Ca	71.4%	***	23
N+K+P+Mg	88.8%	***	22
N+K+P+Ca	89.5%	***	22
N+K+Ca+Mg	89.4%	***	22
N+P+Ca+Mg	86.5%	***	22
K+P+Ca+Mg	80.3%	***	22
N+K+P+Ca+Mg	89.2%	***	21
Concuctivity	60.0%	***	25

Available nitrogen was most highly correlated to yield, but K, Mg, Ca and P were also highly correlated. Addition of more than one nutrient into the equation improves the correlation as can be seen from the table above, the best correlation being given with N+K+Ca vs. yield. The curplot program gave quadratic relationships as the best fit for phosphorus, potassium, magnesium, nitrogen and calcium vs. yield, but as can be seen from the graphs

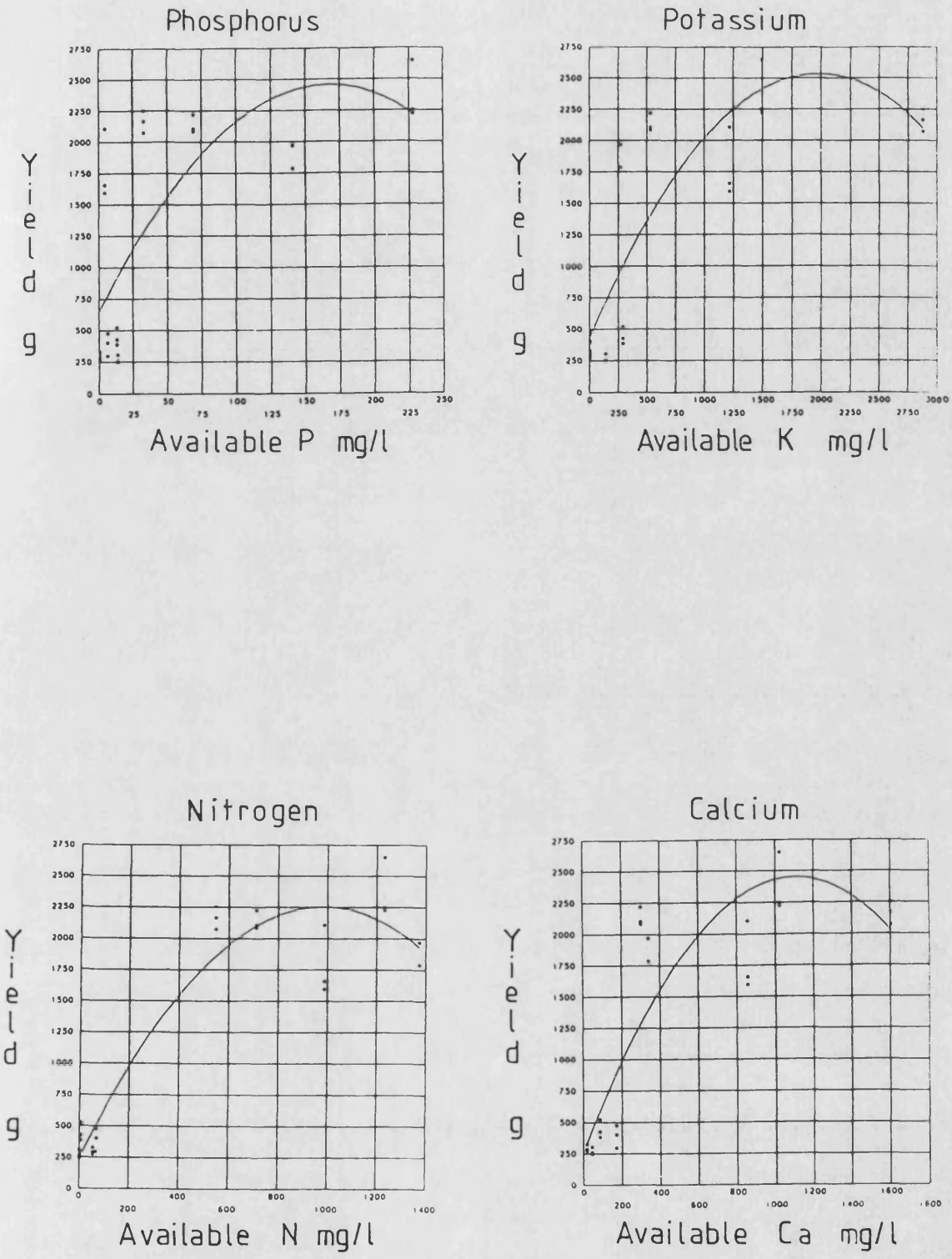


Fig. 3.9 Relationship Between Available Nutrient Levels and Tomato Yield.

(fig. 3.9) the scatter is quite large for each nutrient despite the significant linear correlations. Waller and Wilson (1984) found positive significant correlations for water-soluble nitrogen and phosphorus with growth of tomato (P=0.05). Their study included 17 different commercial growth media and they concluded that no reliable prediction of performance could be made for such a diverse set of media on the basis of any water soluble nutrient analyses. Their levels of significance were, however, lower than tose presented here i.e. their scatter was greater. They also stated that the correlation of water-soluble N with growth was understandable, but that the correlation with phosphorus rate was incidental. This quandary arises here to some extent also. In commercial media where nutrients are added in a balanced form, a medium with high N content will probably also have high P. This is not necessarily the case with the media in this study, however, some correlations between nutrient levels were found here as follows (only those correlated at the P=0.001 level are shown as these are the ones most likely to interfere with statistical analyses):-

Total Nutrients	Correlation Coefficient, r
K vs Zn	0.959
K vs Ca	0.919
P vs Cu	0.970
Zn vs Ca	0.844

Available Nutrients	Correlation Coefficient, r
K vs Zn	0.933
K vs Ca	0.966
Mg vs Cu	0.922
Zn vs Ca	0.871

These highly significant correlations are likely to affect the interpretation of the correlations between yield and leaf nutrient levels i.e. is an increase in growth or yield dependent on the increase in K or the increase in Ca to which K is highly correlated?* The correlations above are of course also incidental; an increase in K level in the medium has no influence over the level of Ca whatsoever.

It appears that available nutrient levels based on the 1:6 water:medium extract can be useful in assessing future tomato yields. Also the existance of significant correlations suggests that the media behave fairly similarly with respect to the analytical technique and with respect to plant growth response to nutrient levels, despite the wide range of organic media used in this study. Scatter may be attributed to physical differences and interactions between nutrients in the media, all affecting plant growth. The evidence suggests that the view of Waller and Wilson (1984) is correct and that predictions based on these correlations would be unreliable.

Total and Available Nutrients (x) vs Leaf Nutrients (y)

Prasad et al (1981a-e) used plant uptake as the criterion for evaluating the 1:1.5 water extract for extracting nutrients from media. Here the same criterion is used to assess the 1:6 water extract method and the total nutrient dry ashing method. Linear regression gave the following results:

* K more likely to limit growth and yield than Ca.

Nutrient	Leaf Harvest Date	r^2 Total	r^2 Available
P	19/7	ns	77.8% *** @
P	22/8	ns	ns
K	19/7	60.1% ***	62.7% ***
K	22/8	83.6% ***	84.4% ***
Mg	19/7	ns	79.4% ***
Mg	22/8	ns	ns
Fe	19/7	ns	ns
Fe	22/8	ns	ns
Cu	19/7	ns	ns
Cu	22/8	ns	ns
Zn	19/7	ns	ns
Zn	22/8	70.5% ***	ns

df=25. FO treatments only used.
@ excluding WW Pig Slurry results.
ns - not significant.

Potassium was the only nutrient significantly correlated to both total and available medium nutrient levels for both leaf samples.

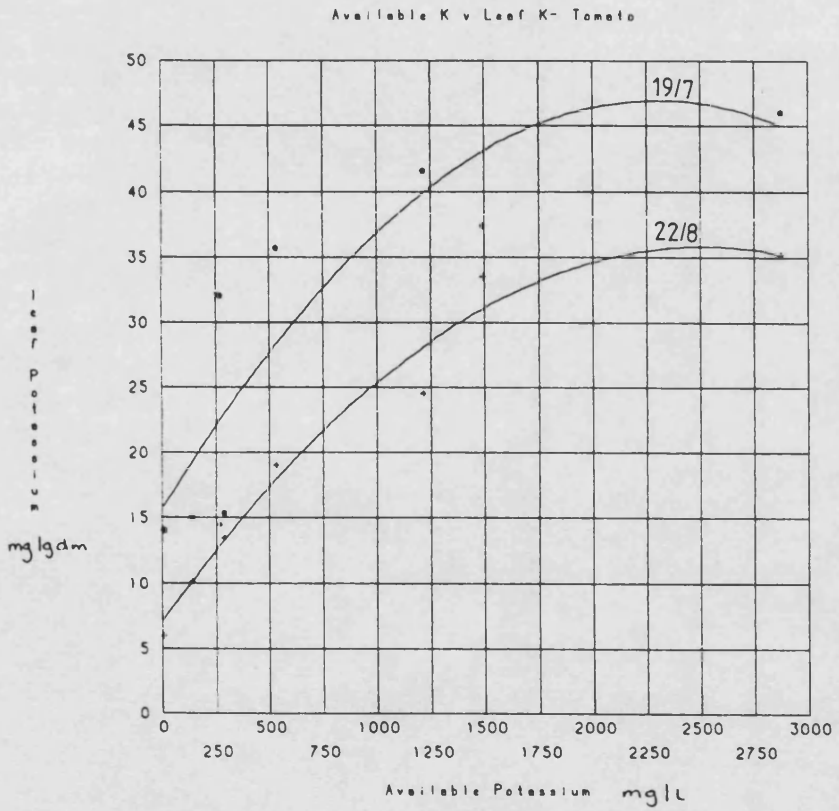
The Curplot program gave quadratic relationships as better fits for all the significant correlations except K19/7 vs. total K and Mg19/7 vs. available Mg. Fig. 3.10 shows some of the curves as plotted by the Curplot program.

The results found here agree with those of Prasad et al (1981e) in that the relationship between medium content and plant uptake is very good for potassium. They also found quadratic relationships, even when all their media were included. Verlodt et al (1985), however, found no relationship between K levels in the substrate and the foliage, but good correlation between initial Mg content of the substrate and Mg

levels in the foliage. This is contrary to my findings and those of Prasad et al. Since no description of the analytical techniques used by Verlodt et al are given it is difficult to assess whether differences between analytical methods may account for these discrepancies. Prasad et al found that there is no general regression equation available for converting one method to another for all substrates since the factor for conversion varies with the substrate. The results found by Verlodt may therefore only hold true for their media (Posidonia oceanica , seagrass substrate) and their analytical methods.

For phosphorus Prasad et al (1981c) found that phosphorus uptake was not constant for all materials. This may explain the failure to obtain correlations in all but one case above. As in this study they also found a quadratic relationship for phosphorus uptake vs. extractable (available) P (1:1.5 extract). Johnson (1980) found good linear correlations between the Levington 1:6 extract method as used in this study and the 1:1.5 extract method for P, K, Mg, pH and conductivity, so the comparisons made here with the work of Prasad et al are valid.

Although medium and leaf nutrient levels do not correlate well in most cases, both leaf and available nutrients correlate well to yield. Plant uptake is perhaps not a particularly good measure for evaluating medium nutrient analysis methods, at least not for the methods used here.



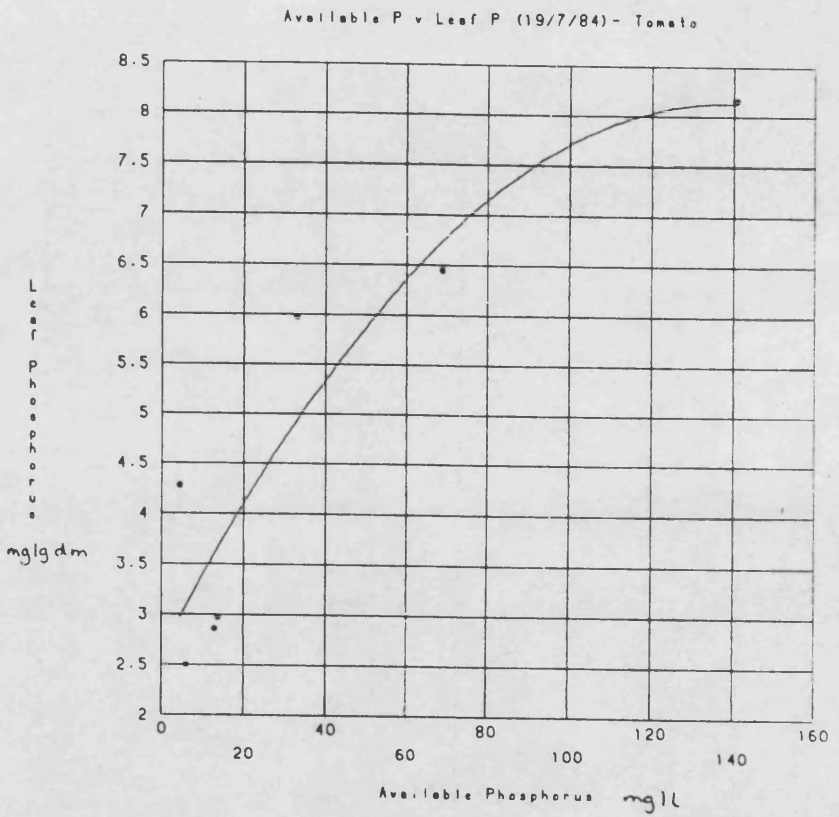


Fig. 3.10 Relationship Between Available Nutrient Levels and Tomato Leaf Nutrient Levels.

Chrysanthemum Trial 1.

Rooted chrysanthemum cuttings Cv. Bright Gold Princess Anne were potted 5 per pot in 14cm half pots containing approximately 850cm^3 of growth medium on the 2nd July 1984 . The cuttings were evenly spaced around the edge of the pot and angled out at 45° . Medium content was standardized by loosely filling the pot, tapping once and scraping the top level with a ruler. The same treatments were used as for the tomato trial, with fertilizer levels as recommended for chrysanthemums (96):-

PPM	ELEMENT	AS
225	Nitrogen	Ammonium nitrate
150	Phosphorus	Super phosphate
200	Potassium	Potassium nitrate
225	Magnesium	Magnesium limestone
1500	Calcium	Ground limestone
	Trace elements	Frit WM 255

The pots were placed under a bench in the glasshouse for the first 48 hours to allow the cuttings to establish themselves, then placed pot thick in three randomised blocks according to the experimental design (fig.3.11). Each plot contained three pots and each block, 27 plots. Guard plants were placed at the ends of each block, and a few were placed down the outer sides of blocks 2 and 3 to prevent damage to the treatment plants whilst moving blackout sheets.

Spot watering was carried out with a hose to give each plant just as much water as required. All plants were pinched out to a minimum of 5 leaves on the 16th July, keeping the height even in each pot

Block 1	Block 2	Block 3	
GGG	GGG	GGG	
LsF1	SF1	BF1	
LvF2	LsFO	SPCF2	
PF2	LsF1	CFO	
LfF2	LvF2	LfF1	
LvFO	SPCF1	LfFO	
LfFO	LfF1	BFO	
MF1	BF1	LvFO	
CF1	PF1	LvF2	
LvF1	MFO	SPCF1	
LfF1	SPCFO	CF1	
LsF2	LfF2	SPCFO	
SPCFO	CF1	LvF1	N
SFO	CFO	BF2	------->
PFO	LsF2	MF1	
SF2	BF2	LsF1	
SF1	PFO	PFO	G=Guard
MFO	LvF1	SFO	
BF2	CF2	PF2	
CF2	LvFO	MF2	
BFO	MF2	SF1	
SPCF2	BFO	CF2	
PF1	MF1	PF1	
MF2	LfFO	LsF2	
BF1	PF2	SF2	
LsFO	SFO	LsFO	
SPCF1	SF2	LfF2	
CFO	SPCF2	MFO	
GGG	GGG	GGG	

Plan of Chrysanthemum Trial 1. Fig. 3.11

where possible, and then spaced to 23x23cm. Growth regulator was sprayed onto all plants on the 17th July at the recommended rate of 0.125% Chlormequat (Alar) and the liquid feed set up using a Cameron diluter (Pressure type Model 'MK' KMKV) to give 250N:150K at each watering. Plants were fed carefully from a watering can to prevent feed splashing onto unfed treatments, as they required watering. Water only was given at weekends.

Blackout facilities were set up on the 25th July. Large sheets of black polythene were pulled over the crop, supported by a metal frame, at 5.00pm each night, and removed at 9.00am each morning, giving a 16 hour night, 8 hour day. This ceased on the 10th September.

At the beginning of August the plants were spaced to 28x28cm centres and sprayed with Fenitrothion and Permethrin against aphis, thrips and caterpillars. Further applications of Chlormequat (0.375%) were made on the 2nd August and 20 days later, as some of the more vigorous treatments were becoming too large.

Disbudding commenced on the 3rd September, to leave one terminal bud per shoot. The most advanced treatments were disbudded first with the last treatment being done on the 17th September.

Phytosieulius persimilis was released onto the crop on the 13th September to combat an infestation of red spider mite (Tetranicus urticae).

The crop was cleared on the 28th September. The following recordings were made:-

Plant Quality

Damage Scores

Every week the plants were compared to SPCF2 for size, browning and yellowing of leaves, orange colouration of stems and leaves and epinasty of stems. Scores were given to each treatment according to the following plan:-

		Shoot length		Break length		
Size	Score	10/7/84	16/7	25/7	3/8	8/8
a	-1	>100mm	>120mm	>15mm	>55mm	>60mm
b	0	⩽100mm	⩽120mm	⩽15mm	⩽55mm	⩽60mm
c	1	⩽70mm	⩽80mm	⩽10mm	⩽35mm	⩽40mm
d	2	⩽40mm	⩽60mm	⩽5mm	⩽15mm	⩽20mm

Size Key: a-Larger than control
b-Same as control
c-Slightly smaller than control
d-Very small compared to control

Browning and twisting of stems

No. of plants	Score
0	0
1-5	1
6-10	2
11-15	3
16-20	4
21-25	5
26-30	6

Orange stems and leaves

No. of Stems + Leaves	Score
0	0
1-15	1
16-30	2

Yellowing of leaves

No. of Plants	Score
0	0
1-7	1
8-15	2

Dead plants

One point per dead cutting (not including accidentally killed plants).

Thus a maximum score for one treatment with 15 live cuttings would be 2+6+2+2=12 and a minimum -1.

A score for SPCF2 other than 0 would be subtracted from all the other treatment scores for that block.

Disbudding

The number of breaks per plant were recorded.

Overall Quality and Form at Harvest

1. Leaf and flower colour - using RHS colour cards.
2. Date first flower opened (1st flat petal).
3. Overall form - compared to an ideal pot chrysanthemum:- 2-2.5 times height of pot, 15-30 flowers (96).

Scores given as follows:- 0-5 for height.
0-5 for shape.

(A total of 10 being for the ideal plant).

4. Dry weight of one or more representative plant per treatment, (the plants were very even within each plot). The leaves and stems were dried for 12 hours at 102°C in a forced aeration oven, removed and weighed after 30 minutes when quite cool.

Analytical Samples

Leaf Samples

Leaves used for dry weight determination at harvest (all the leaves from one or more representative plant). The leaves were washed as for the tomato leaves and stored in plastic bags after drying.

Chrysanthemum Trial 1. Results and Discussion

Damage Scores

Table 3.5 shows the damage scores over time. In general those treatments with relatively high damage scores after 7 days and those with initially low medium nutrient levels (e.g.BFO, LfFO, SFO and SPCFO) declined in quality as can be seen by the increasing damage scores. An explanation for the high damage scores of P, M and Ls are given below.

P and M - Most damage scores were recorded as a result of browning and yellowing of the leaves and stunted growth. High salinity caused poor establishment with wilting and dying of several cuttings. Those plants which survived became yellow, brittle and stunted. High osmotic stress and mass micronutrient deficiency caused by high Ca affecting

the nutrient balance was the likely cause (Bernstein (1964)). A conductivity level of 501 - 600 µs/cm is suggested as the maximum for the initial conductivity of media for chrysanthemums (96).

Ls - Plants were small, pale and with brown marginal necrosis on lower leaves. Upper leaves exhibited interveinal chlorosis. This was attributed to boron toxicity since Gogue & Sanderson (1973) reported similar symptoms in summer grown chrysanthemums. Gogue also found that boron toxicity caused decreased stem length and reduced flower diameter. Plants grown in Lescost were certainly smaller than average.

Breaks per Plant

Fig. 3.12 shows the ANOVA results for the number of breaks per plant. The number of breaks indicate the potential number of flowers in this type of plant since only one bud per break is allowed to develop.

Significant differences were not great since the difference between the highest and lowest number of breaks was only 4. LsF0, LsF1, LsF2, BF0, BF1, MF0, MF2, PF2 and SPCF0 produced significantly fewer breaks than SPCF2. All other treatments were not significantly different to the control. The overall medium effect ANOVA gave Lescost treatments as having significantly fewer breaks than the control (SPC) and Lv as significantly greater. All the other media were not significantly different from SPC.

Treatment		Days from Planting 7	13	22	31	36
Lescost	F0	4.3	3.7	4.0	4.0	6.0
	F1	4.7	4.0	4.7	4.3	6.0
	F2	4.7	5.3	4.0	4.3	5.7
Spent Mushroom	F0	3.3	5.7	6.3	6.3	8.0
	F1	4.7	5.3	6.0	6.3	7.7
	F2	4.0	6.0	6.7	6.3	8.7
Cambark Fine	F0	0.7	3.0	4.0	3.3	3.7
	F1	0.0	1.0	0.7	1.3	2.1
	F2	0.0	1.3	1.0	0.0	1.0
Levington Potting	F0	0.0	1.0	-.3	-.3	-.3
	F1	0.0	0.3	0.7	-1.0	0.3
	F2	0.0	0.7	0.0	-.7	0.0
Leafmould	F0	0.0	3.3	4.0	3.0	4.0
	F1	0.0	0.3	0.3	-.3	1.0
	F2	0.0	0.7	-.7	-.7	0.0
WW Pig Slurry	F0	2.7	5.0	7.3	7.0	9.7
	F1	2.7	5.0	6.7	7.3	8.3
	F2	4.3	5.3	7.3	7.7	8.3
WW Cow Slurry	F0	0.0	3.0	2.7	1.7	1.3
	F1	-.3	3.3	4.0	3.0	2.3
	F2	-.6	3.7	3.7	3.3	3.7
Sedge Peat	F0	0.0	1.0	1.3	0.7	2.3
	F1	0.0	0.0	0.0	0.7	0.7
	F2	0.0	1.0	0.3	-.3	0.7
Sphagnum Peat Control	F0	0.0	1.0	1.7	1.0	2.7
	F1	0.0	0.0	0.3	0.0	1.0
	F2	0.0	0.0	0.0	0.0	0.0

Chrysanthemum Trial 1 Damage Scores.Table 3.5

Dry Weight per Plant (g)

39.9	31.4	29.4	27.5	27.4	27.4	23.2	22.7	21.6	19.9	18.8	18.2	16.0	14.5	11.6	11.5	11.3	11.2	8.7	8.3	8.2	8.2	7.3	6.9	6.5	5.9	3.9
LvF2	LfF2	BF2	LvF1	SPCF2	LvF0	CF2	SF2	SF1	CF0	SPCF1	CF1	LfF1	PF1	SF0	LsF2	MF1	PF0	SPCF0	PF2	BF1	LsF1	MF2	LsF0	MF0	LfF0	BF0

Mean Number of Breaks per Plant

13.8	13.7	13.3	13.3	13.2	12.9	12.8	12.7	12.6	12.5	12.4	12.3	11.7	11.7	11.6	11.3	11.3	11.0	10.7	10.6	10.4	10.2	10.2	10.1	10.1	9.8	9.6
LfF2	SF1	LvF1	LvF0	LvF2	BF2	CF1	SF2	SPCF2	SPCF1	LfF1	CF0	PF1	MF1	SF0	CF2	PF0	LfF0	LsF2	SPCF0	LsF1	BF1	BF0	MF2	MF0	PF2	LsF0

CHRYSANTHEMUM TRIAL 1. ANOVA RESULTS. FIG. 3.12

	EFFECT		
	Treatment	Medium	Fertilizer
Df	54	72	78
LSD 0.05	1.89	1.25	-
LSD 0.01	2.53	1.66	-
LSD 0.001	3.32	2.16	-
f-ratio	3.89***	5.37***	2.91
n	3	9	27

Medium Effect

Number of Breaks/Plant

13.30	12.63	12.41	12.15	11.85	11.11	10.93	10.63	10.22
Lv	S	Lf	C	SPC	B	P	M	Ls

Score for Form and Size at Harvest

This measure represents the quality of the plant at harvest. SPCF2 was taken as the ideal plant, being approximately three times the height of the pot and an ideal shape.

Treatment Effect

Fig. 3.13 shows the results of the treatment effect ANOVA. SF1, SF2, LfF2, BF2, LvF2, LvF1, LvFO and CF2 were not significantly different to SPCF2 in scores for form and size. All the other treatments were of significantly poorer quality.

Score for Form and Size at Harvest.

10.0	9.67	9.67	9.67	9.33	9.33	9.00	9.00	9.00	8.33	8.00	7.67	7.67	6.67	6.67	6.33	6.00	6.00	6.00	5.67	5.67	5.67	5.33	5.33	5.33	5.00	4.70
SPCF2	SF2	LfF2	BF2	LvF1	CF2	SF1	LvF2	LvF0	LfF1	CF0	CF1	SPCF1	LsF2	PF1	MF1	MF0	MF2	PF0	LfF0	BF1	LsF0	LsF1	SF0	SPCF0	PF2	BF0

CHRYSANTHEMUM TRIAL 1. ANOVA RESULTS FIG. 3.13

	EFFECT		
	Treatment	Medium	Fertilizer
Df	54	72	78
LSD 0.05	1.42	1.51	0.92
LSD 0.01	1.90	2.01	1.22
LSD 0.001	2.50	2.61	1.59
f-ratio	12.69***	4.88***	10.96***
n	3	9	27

Medium Effect

score								
9.11	8.33	8.00	7.89	7.67	6.67	6.11	5.89	5.89
Lv	C	S	Lf	SPC	B	M	Ls	P

M, Ls and P were significantly poorer growth media for chrysanthemums overall as measured by form at harvest. The reasons for this were discussed above under the damage score section.

Fertilizer Effect

score		
8.33	7.33	6.19
F2	F1	F0

F2 gave significantly greater scores for form and size at harvest than both F1 (P=0.05) and F0 (P=0.001). F1 was significantly greater than F0 (P=0. 05). Fertilizing the high salinity media (M and P) further decreased quality, however, the dramatic effect on quality of fertilizing the low salinity (nutrient deficient) media far outweighed this effect.

Leaf and Flower Colour and Date of First Open Flower

Table 3.6 shows the colour codes for leaf and flower colour corresponding to RHS colour cards. The reader is advised to refer to these cards, however, the following gives a rough guide to the codes:

Leaf Colours
147 Very dark olive green
137 Mid olive green
146 Yellowy green olive
144 Light yellowy green

A=darkest--->D=lightest.

Flower Colours

All were fairly similar shades of bright yellow.

Date of First Open Flower

The first flower opened on the control treatment 84 days from planting. PF1 was the only treatment which opened earlier at 82 days. Some treatments were considerably later opening, BFO being 10 days and LsFO 9 days later than the control. 84 days appeared to be average for most adequatedly fed treatments. This was supposed to be a 10 week variety, but the blackout facilities were set up a little behind schedule which caused a delay in flower initiation. Also (as will be seen later) all but P treatments were low in copper by harvest, and this can delay flowering as can Mn and Fe deficiency (Machin & Scopes 1978).

Treatment		Leaf Colour	Flower Colour	First Flower Open Day from Planting
Lescost	F0	137c	14b	93
	F1	137c	12a	87
	F2	137b	14a	86
Spent Mushroom	F0	144a	12a	85
	F1	137c	14b	84
	F2	144a	12a	84
Cambark Fine	F0	137a	12a	94
	F1	137b	12a	92
	F2	137a	14b	84
Levington Potting	F0	137a	14b	85
	F1	137b	14a	86
	F2	147a	14b	84
Leafmould	F0	137c	12a	91
	F1	137b	14b	87
	F2	147a	14a	84
WW Pig Slurry	F0	137b	12a	84
	F1	137b	12a	82
	F2	137a	12a	85
WW Cow Slurry	F0	137c	12a	85
	F1	137b	14a	85
	F2	147a	14b	84
Sedge Peat	F0	137b	12a	90
	F1	137b	14a	86
	F2	137c	14a	86
Sphagnum Peat Control	F0	137c	14b	90
	F1	137b	14b	87
	F2	137a	14a	84

Chrysanthemum Trial 1. Leaf and Flower Colours.Table 3.6

Dry Weight per Plant

	EFFECT		
	Treatment	Medium	Fertilizer
Df	54	72	78
LSD 0.05	5.95	7.07	4.81
LSD 0.01	7.96	9.40	6.40
LSD 0.001	10.45	12.23	8.32
f-ratio	20.75***	8.22***	10.56***
n	3	9	27

LvF2 produced significantly heavier plants than any other treatment. LfF2, BF2, LvF1, LvF0, CF2, SF2, and SF1 produced plants not significantly different in weight to the control SPCF2. All the other treatments gave significantly lower dry weights than SPCF2. However, the production of a large plant is not necessarily desirable. In this case frequent applications of growth regulator were required to control the growth of vigorous plants such as those in LvF2. Growth regulator was applied by spray evenly over the whole experiment. This would have accentuated the differences in size between the largest and smallest plants since large vigorous plants would probably be less affected by the growth regulator than small ones at the same dosage (although larger plants would present a bigger target and retain more spray).

Medium Effect

weight per plant (g)

31.57	20.43	18.60	18.31	17.78	13.84	11.32	8.86	8.37
Lv	C	S	SPC	Lf	B	P	Ls	M

Levington Potting Compost gave significantly higher dry weights than any other medium. Ls and M were significantly lower than the control (P=0.01).

Fertilizer Effect

weight per plant		
22.33	16.03	11.32
F2	F1	F0

The treatment ANOVA fig. 3.12 shows how the addition of fertilizer affected plant dry weight for each individial medium, however, overall, liquid feeding significantly increased dry weight over F1 and F0 treatments. This is a similar result to that found for tomato yield.

Photographs 3.3-3.6 show some of the treatments; B representing a low salinity medium, Lv and C intermediate salinity, and P high salinity.

Comparing the different methods of assessing the plants it can be seen that in general the same treatments were 'good' or 'bad' for all the measurement methods. Those treatments with low damage scores at day 36 had high scores for form and size at harvest. These subjective assessments (albeit with the subjectivity limited as much as possible) give useful additional information to measurements such as dry weight and number of breaks, since in this particular case the final product is required in a particular eye pleasing form. Measurement of dry weight alone would not have given sufficient information on the performance of the media.

Ls, M and P came out as consistently poor growth media for chrysanthemums, probably because of their

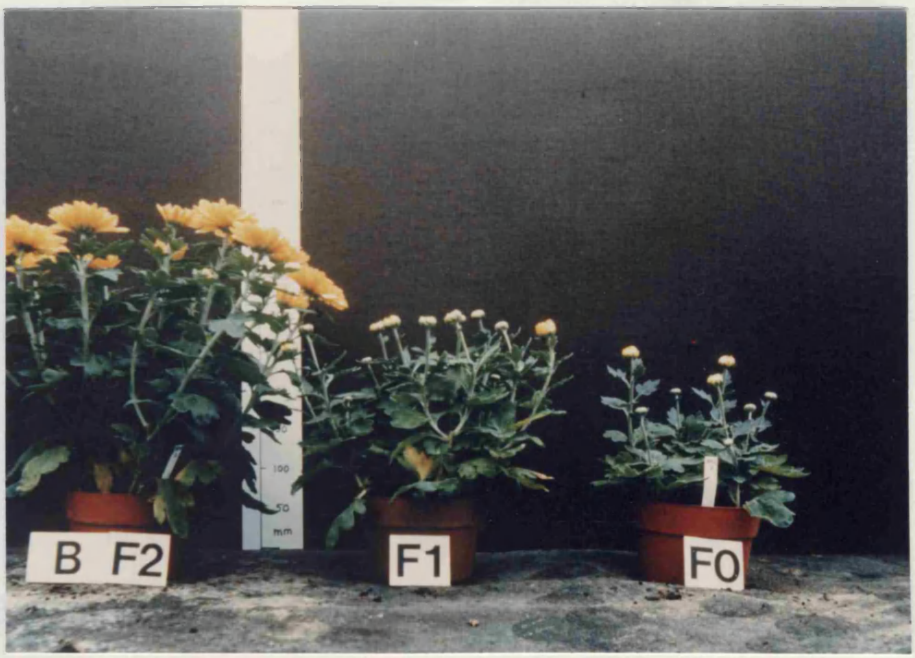


Photo. 3.3 Chrysanthemum 'Bright Gold Anne'.
Low Salinity Medium- Cambark Fine.

Photo. 3.4 Chrysanthemum 'Bright Gold Anne'. Intermediate Salinity Medium- Levington Potting Compost.

Photo. 3.5 Chrysanthemum 'Bright Gold Anne'. Intermediate Salinity Medium- Worm-Worked Cow Slurry.

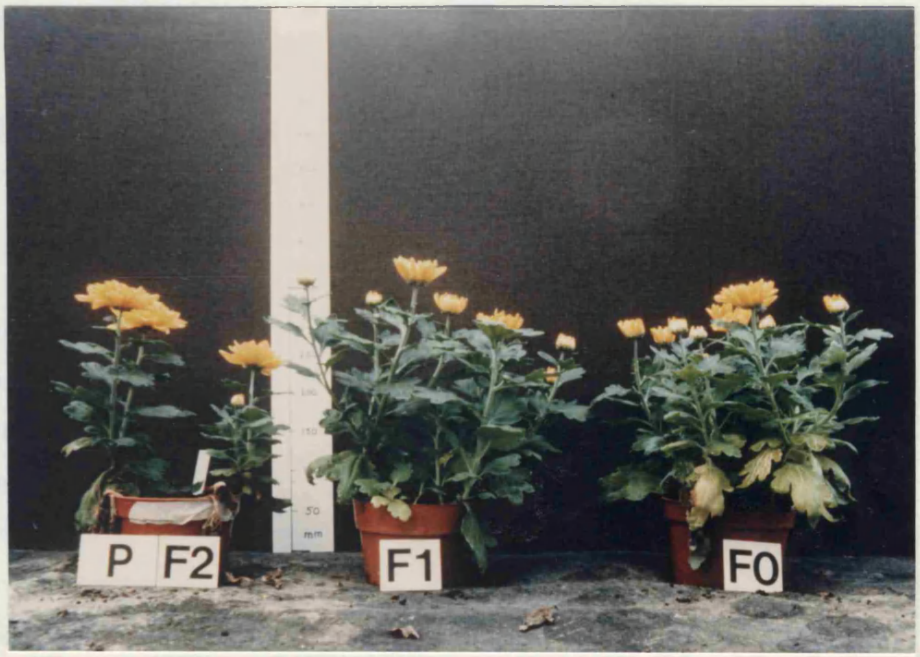


Photo. 3.6 Chrysanthemum 'Bright Gold Anne'. High Salinity Medium- Worm-Worked Pig Slurry.

high soluble salt contents, high pH and excessive boron in Ls. The other media, if fertilized adequately and liquid fed would be equally as good for chrysanthemum production as sphagnum peat. The worm-worked cow slurry would probably perform just as well with liquid feed as the only addition.

Ls, M and P would require dilution with a low salinity medium, or leaching to reduce the conductivity for use in chrysanthemum growing.

Analytical Samples

Leaf Analyses

Table 3.7 shows the leaf nutrient levels (FO treatments only and SPCF2 for comparison). Analyses of variance showed that worm-worked pig slurry grown plants had significantly more phosphorus, magnesium and copper (P=0.001) in the foliage than any other treatment, and plants grown in M had significantly greater K and Zn (P=0.01).

Phosphorus	Deficient	$\leqslant$ 0.2 % dm
	Sufficient	0.3 - 1.0 % dm
	Excess	$\geqslant$ 1.21 % dm

(Peterson 1982)(109)

By harvest time, plants grown in Ls, B, S amd SPC were all deficient in phosphorus. All these media had low availability of phosphorus as can be seen from the medium analysis data (table 2.6). It was predicted that plants grown in Lescost would be likely to be deficient in phosphorus, despite the high total levels found, as the availability was very low and the pH of the medium high. No phosphorus was supplied in the liquid feed for chrysanthemum, and it can be seen that the foliage content of phosphorus in the control, SPCF2, was also on the low side by

Treatment		P mg/g dm	K mg/g dm	Mg mg/g dm	Fe ppm dm	Cu ppm dm	Zn ppm dm
Lescost	F0	1.27	39.3	1.85	53.5	8.4	118
Spent Mushroom	F0	2.82	63.4	5.77	53.2	7.8	454
Cambark Fine	F0	1.65	26.7	3.09	75.8	5.7	266
Levington Potting	F0	3.56	24.5	4.40	95.0	8.5	96
Leafmould	F0	3.10	35.8	2.31	68.8	8.3	176
WW Pig Slurry	F0	6.22	42.6	9.33	73.8	22.5	192
WW Cow Slurry	F0	2.27	24.5	3.87	57.0	7.6	236
Sedge Peat	F0	0.76	22.9	2.00	63.5	4.8	59
Sphagnum Peat	F0	0.92	19.6	2.79	57.2	5.6	206
Control	F2	2.08	32.7	6.55	70.0	4.7	130

Chrysanthemum Trial 1. Leaf Analyses. Table 3.7

NB 1mg/g = 0.1%

harvest time. Worm-worked pig slurry was the only medium still supplying plentiful amounts of phosphorus by this stage, although levels of phosphorus in Lv and Lf grown plants were just sufficient.

Potassium	Deficient	$\leqslant$ 3.5 % dm
	Sufficient	4.5 - 6.5 % dm
	Excess	$\geqslant$ 6.61 % dm (109)

BFO, LvFO, CFO, SFO, SPCFO and SPCF2 were all deficient in potassium at harvest. Ls, Lf and P were a little low in potassium, and M was the only treatment with sufficient. These results are understandable if the initial medium K contents are considered. Leafmould, initially low in available nurients was apparently able to supply nutrients from its moderate reserve of total nutrients. Continued breakdown of the leafmould would be responsible for the release of these nutrients.

Magnesium	Deficient	$\leqslant$ 0.14 % dm
	Sufficient	0.35 - 0.65 % dm
	Excess	0.71 % dm (109)

None of the treatments were deficient in Mg at harvest, although Ls, B, Lf, S and SPCFO were all low in this nutrient. SPCF2, C, Lv and M all had sufficient Mg, whilst P had excess. The initial available nutrient levels can explain these findings in most cases excepting those for Lescost. This medium had a relatively high level of Mg, both total and available. The high pH (7.65) may be responsible for suppressing the uptake of Mg, but then M also had a high pH (7.88) and a high K:Mg ratio which would be expected to suppress Mg uptake further, M however, had sufficient Mg in the foliage.

Iron	Deficient	⩽ 50 ppm dm
	Sufficient	60 - 500 ppm dm
	Excess	⩾ 526 ppm dm (109)

None of the treatments were deficient in iron at harvest, but Ls, M, C and SPC were all on the low side. All the rest of the treatments had sufficient Fe, with Lv the most.

Worm-worked cow slurry grown plants exhibited chlorosis of upper leaves, similar to that caused by iron deficiency early on in the experiment. This later disappeared, but may have been caused by the depressive effect on iron uptake of high phosphate and nitrate levels, low manganese level and a high K:Ca ratio in the medium.

Copper	Deficient	⩽ 5 ppm dm
	Sufficient	25 - 75 ppm dm
	Excess	⩾ 81 ppm dm (109)

SPCF2 and SFO were both deficient of copper by harvest time. All treatments but P were low in copper. P at 22.5ppm was close to sufficiency level. This was as expected from the initial medium level of copper in worm-worked pig slurry, which was execptionally high in comparison to the other media.

Zinc	Deficient	⩽ 15 ppm dm
	Sufficient	15 - 50 ppm dm
	Excess	⩾ 56 ppm dm

According to the above criteria (Peterson 1982) all the treatments had excess Zn in the foliage. However, Sanderson (1980) found 320 and 67 ppm dm in two different cultivars of chrysanthemum grown in sphagnum peat, and considerably higher levels in plants grown in sewage refuse compost without any visible Zn toxicity symptoms, although a negative correlation was found between growth and foliar Zn.

Williamson et al (1981) quote 400 ppm dm as the tolerable limit of Zn in leaves for most plants, whilst > 200 ppm dm is regarded as the phytotoxic level by Davis (1979). Only plants grown in M had > 400 ppm dm foliage Zn. This level was probably phytotoxic. No explanation is obvious for B and SPC treatments having relatively high levels of Zn in the leaves. Both had very low initial available levels in the medium and the pH of B was > 6 at which the availability of Zn begins to be reduced. An explanation may be that poor growth in these two media resulted in little requirement for Zn during the growth period thus much of the initial medium content may still have been present at harvest, whilst other treatments had used up their supplies. A medium analysis at harvest would have been desirable to clarify this point.

Evaluation of Analytical Techniques

Leaf nutrient, total and available medium nutrient levels were correlated to dry weight of plants at harvest. FO treatments only were used. No significant correlations were found between leaf nutrient levels and dry weight or between medium total nutrient levels and dry weight.

Available P (P=0.05) and N (P=0.01) were found to be significantly correlated to dry weight at harvest, whilst Mg, Ca and K were not. Multiple correlation techniques were used to correlate combinations of these nutrients to dry weight. The lack of linear correlations with dry weight are not surprising, since some of the media were too saline for chrysanthemum and caused reduced growth. Potassium and calcium contributed most to the conductivity of the medium extracts. Both these nutrients (available levels) were highly correlated to the conductivity (P=0.001). Available Mg was also significantly correlated (P=0.05). Phosphorus unsurprisingly, was not significantly correlated but perhaps more surprisingly neither was nitrate-N. The likely relationship between conductivity (or those elements mainly responsible for the conductivity i.e. Ca and K) and dry weight of chrysanthemum would be a normal distribution, such as that plotted for available Ca vs. dry weight in fig. 3.14 . A linear correlation would be possible either side of the peak of the curve as in the case of tomato where the conductivity and elemental content of the media does not become excessive and repress growth (the salinity threshold level, at which yield begins to decline for tomato is reported as 2500 µs/cm (Maas & Hoffman (1977)) i.e. the use of very salt sensitive or salt tolerant species are recommended when assessing analytical

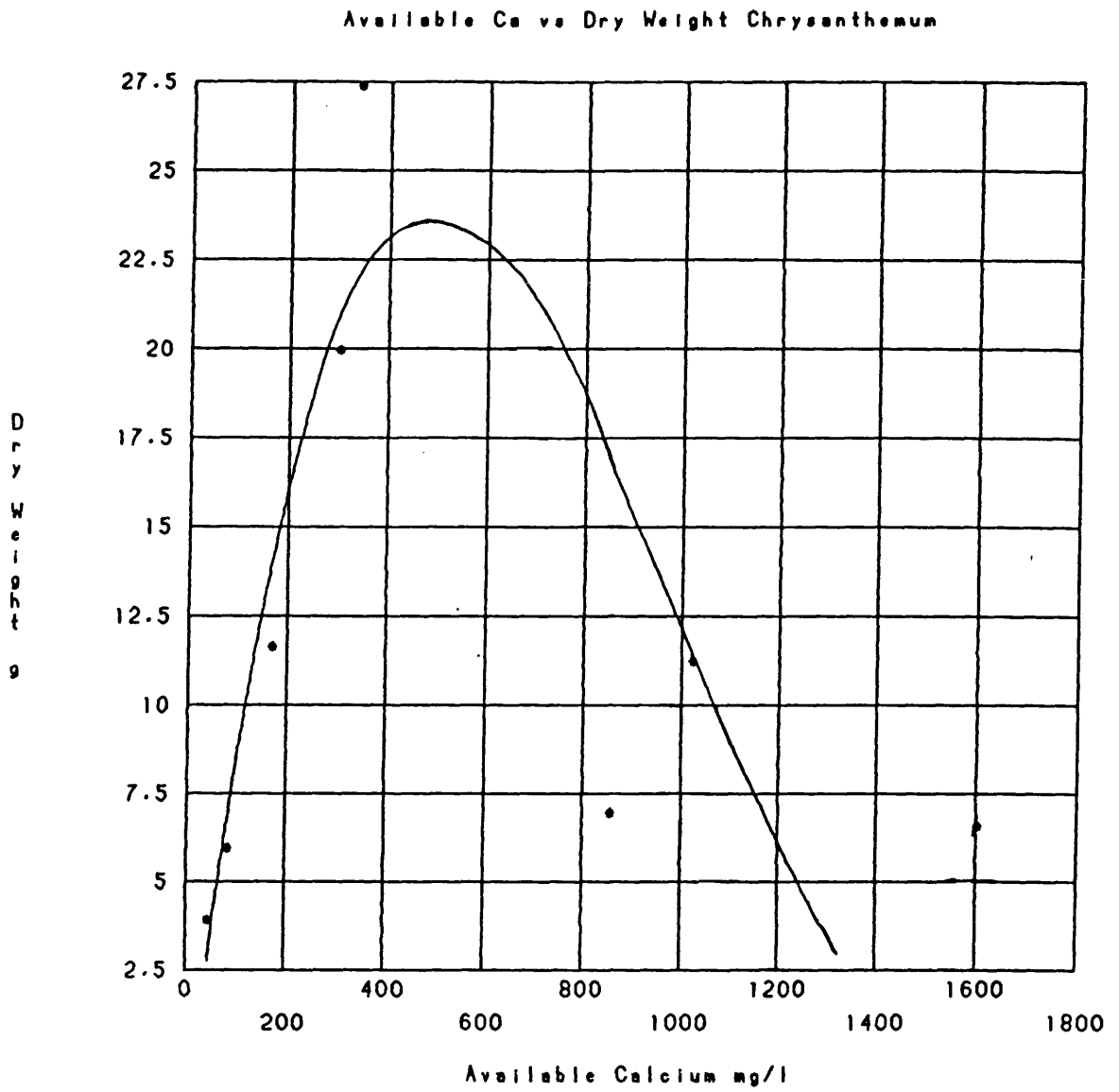


Fig. 3.14 Normal Distribution of Available Calcium vs. Chrysanthemum Dry Weight.

techniques by linear correlations between medium or leaf nutrients and growth.

Although several combinations of the above mentioned available nutrients were significantly correlated to dry weight, the interpretation of these correlations is complicated by the fact that normal distributions of nutrient level against dry weight are likely for Ca, K and Mg. The use of chrysanthemum is not therefore recommended as a test plant for assessing analytical techniques by linear correlations over such a wide range of media salinity levels.

Total and Available Nutrients vs. Leaf Nutrients

As in the tomato experiment nutrient uptake was used to assess the available and total nutrient analysis methods. Leaf nutrient levels were correlated to both total and available nutrients with the following results:-

	r^2		
NUTRIENT	TOTAL	AVAILABLE	df
P	80.4% ***	81.7% ***	26
K	93.3% ***	90.3% ***	26
Mg	ns	83.0% ***	26
Fe	ns	ns	26
Cu	93.9% ***	87.7% ***	26
Zn	19.8% *	58.3% ***	26

In the case of copper no correlation would have been present had the figures for worm-worked pig slurry been excluded as can be seen from fig. 3. 15. Insufficient mid-range points was again a problem in determining the validity of the relationships. As in the previous cases the correlations serve best to

show trends rather than for use in actual predictions (see fig. 3.15).

A greater number of significant correlations between medium and leaf nutrient levels were found for chrysanthemum than tomato. Chrysanthemum may be less able to control the uptake of nutrients than tomato, acting more like a 'sponge' in taking up nutrients. Chrysanthemum, therefore, apparently provides a better test plant than tomato for indicating medium nutrient content by the criterion of plant uptake.

The curplot program gave degree 2 (quadratic) relationships as better fits for total K or available K vs. leaf K and for available Cu vs. leaf Cu.

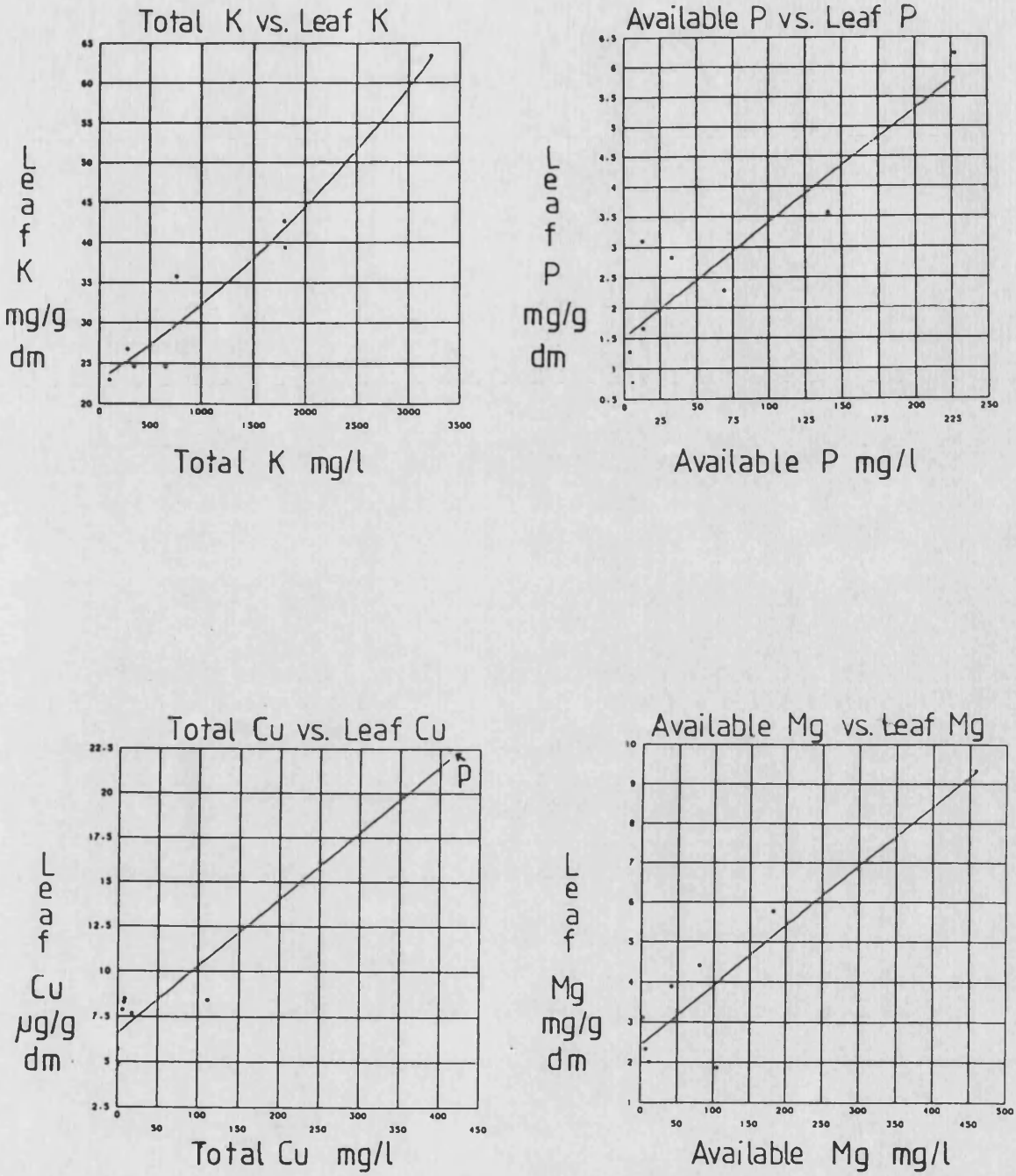


Fig. 3.15 Relationships Between Total and Available Nutrient Levels and Chrysanthemum Leaf Nutrient Levels.

Chrysanthemum Trial 2.

A chrysanthemum trial was set up on 13/6/85 to compare growth media when physically and chemically amended. The same cultural methods were used as for the first chrysanthemum trial, with materials as follows:-

1. Rooted cuttings of Chrysanthemum morifolium Cv. Gay Anne.
2. Growth media-amended as follows (96):-

Control (SPC) 100% Sphagnum Peat

	Plus:-	Kg/m^3	
		0.4	Ammonium nitrate
		1.5	Super phosphate
		0.75	Potassium nitrate
	Base	2.4	Ground limestone
	Dressing	2.4	Magnesium limestone (12% Mg)
		0.375	Frit WM 253A

Supplying:-	PPM
	230 Nitrogen
	120 Phosphorus
	290 Potassium
	290 Magnesium
	1740 Calcium

Bark (B)

B1 100% Cambark Fine + 100% base dressing.

B2 1:1 Cambark Fine:Sphagnum Peat + 100% base dressing.

B3 1:1:1 Cambark Fine: Sphagnum Peat:Vermiculite (Silvaperl Horticultural Grade) + 100% base dressing.

All the following media were amended to the recommended nutrient levels using the fertilizers above according to the available nutrient analyses (table 2.8). No attempt was made to reduce excessive levels already present (except for M1). The physico-chemical and physical properties of these amended media can be seen in table 3.9.

Spent Mushroom Compost (M)

M1 100% Spent Mushroom Compost leached (12 litres of compost leached with 21 litres tap water).

M2 1:1:1 M:B:Sphagnum Peat (SP).

M3 1:1:1 M:Vermiculite(V):SP.

Doncaster Sewage/Refuse Compost (D)

D1 100% D

D2 1:1 D:Perlite(Silvalite Grade 35) (PL)

D3 1:1:1 D:B:PL

Leafmould (Lf) Kew, 3 year old.

Lf1 100% Lf.

Lf2 3:1 Lf:SP

Lf3 2:1:1 Lf:SP:V

Worm-Worked Pig Slurry (P) 1985 sample.

P1 1:2:1 P:SP:V

P2 1:1 P:B

P3 1:1 P:V

Worm-Worked Cow Slurry (C) 1985 sample.

C1 1:2:1 C:SP:V

C2 1:1 C:B

C3 1:1 C:V

Composted Pig Slurry (RP) G.F.Shattock,Reading.

RP1 1:2:1 RP:SP:V

RP2 1:1 RP:B

RP3 1:1 RP:V

Bark was used in mixtures with M,P,C,D and RP because of its ability to absorb (and release) nutrients, vermiculite was also used for the same reason. Both these materials also help to increase the aeration, and decrease the bulk density of these growth media mixtures because of their relatively low densities and large particle size. Perlite was used with D to reduce the bulk density and improve aeration, it also had the effect of 'diluting' the salinity of the compost, as did B and V in the above mentioned mixtures. Peat was used as a diluent in the more saline composts and to improve water retention in the mixtures with bark.

Five cuttings were potted per 14cm half pot, with three pots/plot and 3 plots/medium. The experiment was laid out according to the experimental plan (fig. 3.16). 0.125% Chlormequat (Alar) was applied on

24/6/85 and 0.375% on 5/7/85 and 26/7/85. The tops of the plants were pinched out to 5 leaves on 1/7/85, and blackouts were used from 5/7/85 until 15/8/85 to reduce the daylength to 8 hours. Feed was applied through the watering system equally to all plants twice a week. Liquid feed was the same as for the first trial. The plants were disbudded to leave one bud per break on 7/8/86.

The following insecticidal sprays were applied:-

9/8/85 Dicofol and dimethoate* vs. red spider and aphis.
12/8/85 Cypermethrin vs. white fly.
15/8/85 Gamma-HCH vs. Earwigs.

* This organophosphorus insecticide was sprayed in error, and caused some damage to the plants in the form of marginal chlorosis. It had no other apparent detrimental effect.

The experiment was harvested on 16/9/85.
The following recordings were made:-

Damage Scores

As for the first chrysanthemum trial with the following alterations:-

	Stem Length	Break Length					Bud Width
Score	2/7/85	9/7	17/7	31/7	7/8	15/7	23/8
-1	>190	>30	>50	>130	>160	>180	>20mm
0	⩽190	⩽30	⩽50	⩽130	⩽160	⩽180	⩽20mm
1	⩽140	⩽20	⩽30	⩽90	⩽100	⩽110	⩽15mm
2	⩽90	⩽10	⩽10	⩽30	⩽40	⩽40	⩽10mm

Pre-harvest

1. Dry weight of pinchings.
2. Date first flower opened on each plot.
3. Flower and leaf colour, (R.H.S. colour cards), 10/9/85.
4. Diameter of fully opened flower. (Mean diameter calculated from 4 fully opened flowers per plot).

Plants at Harvest

1. Scores for form and size (as for first trial).
2. Mean number of breaks per plant.
3. Dry weight of 'plant', breaks and flowers only, these being severed at their join with the stem.

N.B. At harvest the term 'plant' refers to the pot of 5 plants.

Block 1	Block 2	Block 3	
GGG	GGG	GGG	
B3	C2	M2	
C1	C1	D1	
D3	RP2	C2	
D2	M3	P1	
Lf3	D2	M2	
SPC	P2	B1	
Lf2	M1	C1	
Lf1	RP1	D3	N
C2	RP3	B3	------->
C3	D3	SPC	
B2	B2	B1	
M3	B3	D2	G=Guard
M1	M2	RP1	
P1	Lf2	Lf2	
RP1	D1	RP2	
RP2	P3	B2	
RP3	Lf3	P2	
P3	P1	C3	
D1	C3	Lf3	
P2	Lf1	P3	
M2	SPC	Lf1	
B1	B1	RP3	
GGG	GGG	GGG	

Plan of Chrysanthemum Trial 2. Fig 3.16

Chrysanthemum Trial 2. Results and Discussion.

Damage Scores.

Table 3.8 shows the damage scores with time. Several of the treatments had negative damage scores by the 71st day of the experiment. These plants were superior in size to the control. Only M1 was particularly poor after 71 days. Other treatments with high damage scores after 19 days had improved considerably by 71 days (see photograph 3.7). Table 3.9 gives the physicochemical properties of the media. All those with greater than index 4 for conductivity were above the level recommended for media for chrysanthemums. These conductivity levels are reflected in the damage scores. It appears that most media were eventually leached to suitable levels, but in the case of M1 the post harvest conductivity level was still excessively high.

Plants in D exhibited chlorosis similar to that caused by Mn deficiency (Machin & Scopes 1978) (see photograph 3.8) The relatively high pH of the medium may have been responsible for causing such a deficiency since the availability of Mn is greatly reduced between pH 7 and 8 (Bunt 1976).

Breaks per Plant.

Fig. 3.17 shows the ANOVA results for the effect of treatment.

df	44
LSD 0.05	1.4
LSD 0.01	1.9
LSD 0.001	2.5
f-ratio	2.10 *
n	3

M1 had significantly fewer breaks than all the other treatments (P=0.05). SPC was not significantly different to the rest of the treatments excepting M1.

Treatment		Days from Planting 19	26	34	48	55	63	71
Doncaster	1	0.7	1.3	1.0	1.0	1.7	2.0	1.0
	2	1.0	1.7	1.0	1.0	1.0	1.0	1.3
	3	0.3	1.3	0.3	1.0	1.0	1.3	0.3
Cambark	1	0.0	0.3	0.3	0.7	1.0	1.0	0.0
Fine	2	0.0	0.3	0.0	0.0	0.3	0.0	0.0
	3	-.3	0.0	0.3	0.3	0.7	0.0	0.0
Spent	1	4.3	5.3	5.0	5.0	5.0	5.0	5.0
Mushroom	2	4.7	5.7	5.0	2.3	2.0	1.3	0.3
	3	3.7	6.0	3.7	2.0	1.7	1.0	-.3
Leafmould	1	0.3	0.3	0.0	0.3	0.7	0.0	-.3
	2	0.0	0.3	0.0	0.3	0.0	0.3	-.3
	3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
WW Pig	1	1.7	2.7	1.3	0.3	0.3	0.0	-.3
Slurry	2	3.7	4.3	2.7	1.0	1.0	0.3	-.3
	3	3.7	4.7	3.0	1.0	0.7	0.3	-.7
WW Cow	1	0.0	0.7	0.3	-.3	0.0	0.0	0.0
Slurry	2	2.3	3.3	1.3	0.7	1.0	0.3	0.0
	3	2.0	3.0	1.0	0.7	0.3	0.0	-.7
Pig	1	0.3	1.3	0.0	-.3	-.7	-.3	-.7
Slurry	2	1.7	2.0	1.0	0.7	1.0	0.0	-.7
Compost	3	1.3	2.0	1.0	0.3	0.3	0.0	-.7
Sphagnum Peat Control		0.0	0.0	0.0	0.0	0.0	0.0	0.0

Chrysanthemum Trial 2 Damage scores. Table 3.8

Treatment		pH	Conductivity us\cm	INDEX	Bulk Density mg/1 *
Doncaster	1	7.07	1031	7	367
	2	7.12	673	5	221
	3	6.92	565	4	208
Cambark	1	5.98	397	2	154
Fine	2	5.33	427	3	119
	3	6.13	429	3	125
Spent	1	6.98	2171	>9	232
Mushroom	2	5.93	1367	>9	148
	3	6.00	1507	>9	156
post harv.	1	6.83	747	6	207
Leafmould	1	6.60	580	4	237
	2	6.73	630	5	197
	3	6.68	593	4	199
WW Pig	1	5.90	729	6	123
Slurry	2	6.27	1019	7	166
	3	Insufficient remaining for analysis.			
WW Cow	1	5.45	697	5	107
Slurry	2	6.47	841	6	130
	3	Insufficient remaining for analysis.			
Pig	1	5.68	578	4	114
Slurry	2	6.23	857	6	140
Compost	3	6.95	819	6	141
Sphagnum Peat control		4.57	509	4	87

* Bulk density measured by FIBSPAN method.

Chrysanthemum Trial 2. Properties of Media. Table 3.9

Number of Breaks per Plant.

12.0	11.8	11.7	11.6	11.5	11.4	11.4	11.2	11.2	11.0	10.9	10.8	10.7	10.7	10.7	10.7	10.6	10.4	10.4	10.3	10.2	8.7
RP1	M3	P3	SPC	P1	Lf1	P2	C3	C1	B2	B1	RP3	C2	D1	M2	RP2	Lf3	D3	Lf2	B3	D2	M1

Flower Diameter (mm).

111	110	107	106	105	104	103	103	103	102	102	101	101	99	98	98	96	95	94	87	86	77
RP3	RP1	P1	P3	P2	M3	RP2	C1	Lf3	Lf2	C3	M2	C2	SPC	B2	Lf1	D3	B3	B1	D2	D1	M1

CHRYSANTHEMUM TRIAL 2. ANOVA RESULTS FOR NUMBER OF BREAKS PER PLANT AND FLOWER DIAMETER. FIG. 3.17

Scores for Form and Size at Harvest.

The results of the treatment effect ANOVA are presented in fig. 3.18.

df	44
LSD 0.05	0.9
LSD 0.01	1.2
LSD 0.001	1.6
f-ratio	28.70 ***
n	3

The score for SPC was significantly greater than those for B1 (P=0.05), D1, D3 (P=0.01), D2 and M1 (P=0.001). Other treatments were not significantly different to SPC. Plants in D treatments were pale with thin spindly stems. B1 plants also had thin weak stems, but were a good colour, whilst plants in M1 were stunted with excessive chlorosis of the leaves (see photograph 3.7).

Leaf and Flower Colour and Date of First Open Flower.

Table 3.10 gives the leaf and flower colours and date of first open flower (see page 116 for explanation of leaf colours). The RHS colour codes correspond approximately to the following flower colours:-

24 pale orange
26 dusty pinky orange
31 dusty orangy red

The normal number of days to the first flower opening appeared to be 88. Plants in RP and P were a few days earlier in opening , and in D treatments and M1 one or two days later. Delayed flowering, thin stems and uniform chlorosis as seen in D are all possible symptoms of Mn deficiency.

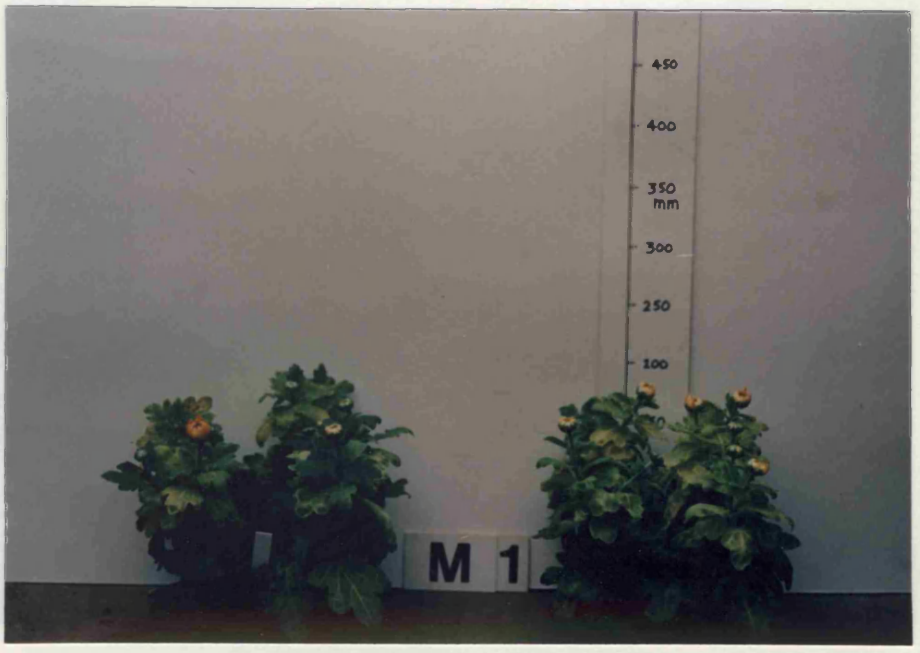


Photo. 3.7 Chrysanthemum 'Gay Anne'
100% Leached Spent Mushroom Compost.

Photo. 3.8 Chrysanthemum 'Gay Anne'
100% Doncaster Sewage/Refuse Compost.

Photo. 3.9 Chrysanthemum 'Gay Anne'
1:1:1 M:vermiculite:sphagnum peat.

Photo.3.10 Chrysanthemum 'Gay Anne'
1:1 P:vermiculite.

Scores for Form and Size at Harvest.

10	10	10	10	10	10	9.7	9.7	9.7	9.7	9.7	9.3	9.3	9.3	9.0	9.0	9.0	8.3	8.0	8.0	7.0	2.0
M3	P2	P3	RP1	RP2	RP3	M2	Lf2	P1	C1	C3	C2	SPC	B2	B3	Lf1	Lf3	B1	D1	D3	D2	M1

CHRYSANTHEMUM TRIAL 2. ANOVA RESULTS FOR SCORES FOR FORM AND SIZE AT HARVEST. FIG. 3.18

Treatment		Leaf Colour	Flower Colour	First Flower Open Day from Planting
Doncaster	1	146b	24a	90
	2	146a	26a	89
	3	137a	31b	89
Cambark Fine	1	137a	31b	88
	2	147a	31b	88
	3	147a	26a	89
Spent Mushroom	1	144c	26a	90
	2	137a	31b	88
	3	137a	31b	86
Leafmould	1	137a	26a	87
	2	147a	31b	85
	3	137a	26a	87
WW Pig Slurry	1	147a	31a	85
	2	137a	31a	87
	3	147a	26a	85
WW Cow Slurry	1	147a	31b	88
	2	137a	31b	88
	3	137a	31b	86
Pig Slurry Compost	1	147a	31b	85
	2	137a	26a	85
	3	137a	31b	84
Sphagnum Peat control		147a	31b	88

Chrysanthemum Trial 2. Leaf and Flower Colours.Table 3.10

Flower Diameter

Fig. 3.17 shows the treatment effect ANOVA for flower diameter.

df	44
LSD 0.05	6.8
LSD 0.01	9.2
LSD 0.001	12.0
f-ratio	11.35 ***
n	3

D2 (P=0.01), D1 and M1 (P=0.001) had significantly smaller flowers than SPC, whilst RP3, RP1 (P=0.01), P1 and P3 (P=0.05) had significantly larger flowers.

Dry Weight of Pinchings

Fig. 3.19 gives the treatment effect ANOVAs for dry weight of pinchings and dry weight at harvest.

	Dry Weight	
	Pinchings	Harvest
df	44	44
LSD 0.05	1.563	5.64
LSD 0.01	2.091	7.55
LSD 0.001	2.746	9.92
f-ratio	22.51***	10.83***
n	3	3

Since all plants were pinched down to 5 leaves the dry weight of pinchings represents the amount of growth which occurred prior to pinching (18 days from planting) plus a proportion of the original cutting. Cuttings were standardized at potting to ensure each plot contained cuttings of equal size. Only B2, RP1, Lf2, Lf1 and C1 were not significantly smaller than SPC (in terms of dry weight) at the time of pinching.

Dry Weight of Pinchings (g).

9.84	9.76	9.30	9.21	8.86	8.47	8.10	7.89	7.80	6.78	6.31	5.98	5.59	4.78	4.31	4.31	3.65	3.46	2.76	2.73	2.64	2.30
B2	SPC	RP1	Lf2	Lf1	C1	Lf3	B3	B1	P1	D1	D3	D2	C2	RP2	M3	C3	RP3	P3	P2	M2	M1

Dry Weight of Plant at Harvest (g).

32.7	31.0	30.3	29.7	29.2	27.7	27.6	27.3	26.1	25.3	24.8	24.6	23.9	23.8	23.6	22.2	20.9	20.1	19.9	15.3	13.0	4.5
RP1	Lf3	C1	SPC	P1	M3	RP3	P3	B2	B3	P2	Lf2	Lf1	C2	C3	RP2	M2	B1	D3	D1	D2	M1

CHRYSANTHEMUM TRIAL 2. ANOVA RESULTS FOR DRY WEIGHT. FIG. 3.19

Dry Weight at Harvest

Lf1, C2, C3, RP2 (P=0.05), M2, B1, D3 (P=0.01), D1, D2 and M1 (P=0.001) were all significantly lower in dry weight than SPC. P treatments had improved greatly when compared to the control (SPC) from the pinching time.

RP1, C1 and P1 gave the largest plants of the animal waste mixes. These contained 1:2:1 animal slurry compost:sphagnum peat:vermiculite. The other mixes were 1:1 waste:bark (treatment 2) and 1:1 waste:vermiculite (treatment 3). The salinity and pH of the 1:1 mixes were probably initially too high (see table 39) and restricted growth a little. The quality of plants at harvest was, however, at least as good if not better in the 1:1 animal slurry compost:bark or vermiculite mixes (see scores for form and size above).

Lf3 gave significantly larger plants than Lf1 or 2. This mix had the least leafmould of the three and included a proportion of vermiculite which may have improved the cation exchange capacity. There was little difference between the three treatments in terms of pH or conductivity or between Lf2 and Lf3 for bulk density. The better growth in Lf3 may be attributable to improved air and water relations via an improvement in the particle size distribution. Air and water capacity were not measured in the chrysanthemum media so this possibility cannot be proved.

M3 produced significantly larger plants than M1 and M2. M3 contained 33% spent mushroom compost with equal quantities of vermiculite and sphagnum peat. M2 was similar, with bark instead of vermiculite in the mix. The improvement in growth is again attributable to a difference in air and water relations between the bark and vermiculite mixes or possibly to a

difference in cation exchange capacity between bark and vermiculite; vermiculite having a much greater CEC (150me/100g) than bark ($\simeq$ 36me/100g)(Bunt 1976). NB The bulk density of the vermiculite mixture (M3) is slightly higher than that of the bark mixture (M2) which means that slightly more vermiculite in terms of weight was present in 1 litre of M3 than bark in M2, thus increasing the difference in CEC further.

Overall Comparison of Media

Several of the mixes which appeared poor for chrysanthemum growth at the start of the experiment because of high initial salinity levels gave excellent quality plants by harvest time (e.g. M3, RP and P treatments, see photographs 3.9 & 3.10). This would not be acceptable to a commercial grower, who would need to be reassured that the plants were growing well at all times. This experiment was conducted in the summer when frequent watering was necessary. Leaching of the medium may therefore have occurred. This may not happen so rapidly in a winter grown crop. On the other hand high transpiration rates of plants during the summer months would serve to exacerbate the effect of high salinity in the medium, by concentrating the soil solution, if the moisture content was not maintained at a high level.

Only D mixes were consistently poor growth media. The high pH was cited above as a possible explanation. In addition the inclusion of perlite and bark in the mixes may have reduced the water holding capacity of the medium to below that which was optimal. The water holding capacity of D was already lower than for most of the other media (see table 2.9).

This experiment was largely successful in that an

attempt was made to amend the waste composts to produce media roughly equal in ability to grow good quality pot chrysanthemums. Differences between the treatments were not great by harvest time on the whole, M1 and D treatments being the only exceptions.

Evaluation of Analytical Techniques

Bulk density (FIBSPAN), pH and conductivity (µs/cm) were correlated to dry weight of chrysanthemum pinchings and dry weight at harvest. Simple and multiple correlation techniques were used with the following results:-

Dry Weight at Harvest

Parameter	r^2%	Significance Level	df
pH	21.0	*	16
us/cm	0.0	-	16
Bulk density (BD)	25.2	*	16
$(pH)^2$	15.2	-	16
$(us/cm)^2$	-5.6	-	16
pH+us/cm	21.6	-	15
$(pH)^2+(us/cm)^2$	13.0	-	15
pH+BD	21.9	-	15
$(pH)^2$+BD	38.2	*	12
us/cm+BD	20.4	-	15
$(us/cm)^2$+BD	31.9	*	12
pH+us/cm+BD	16.4	-	14
$(pH)^2+(us/cm)^2$+BD	32.6	-	11

$(pH)^2$ and $(us/cm)^2$ were included as the Curplot program gave quadratic relationships as the best fit for pH vs dry weight at harvest and conductivity vs dry weight at harvest and dry weight of pinchings (see fig. 3.20). Squaring pH and conductivity did not improve the simple correlations, but did improve the

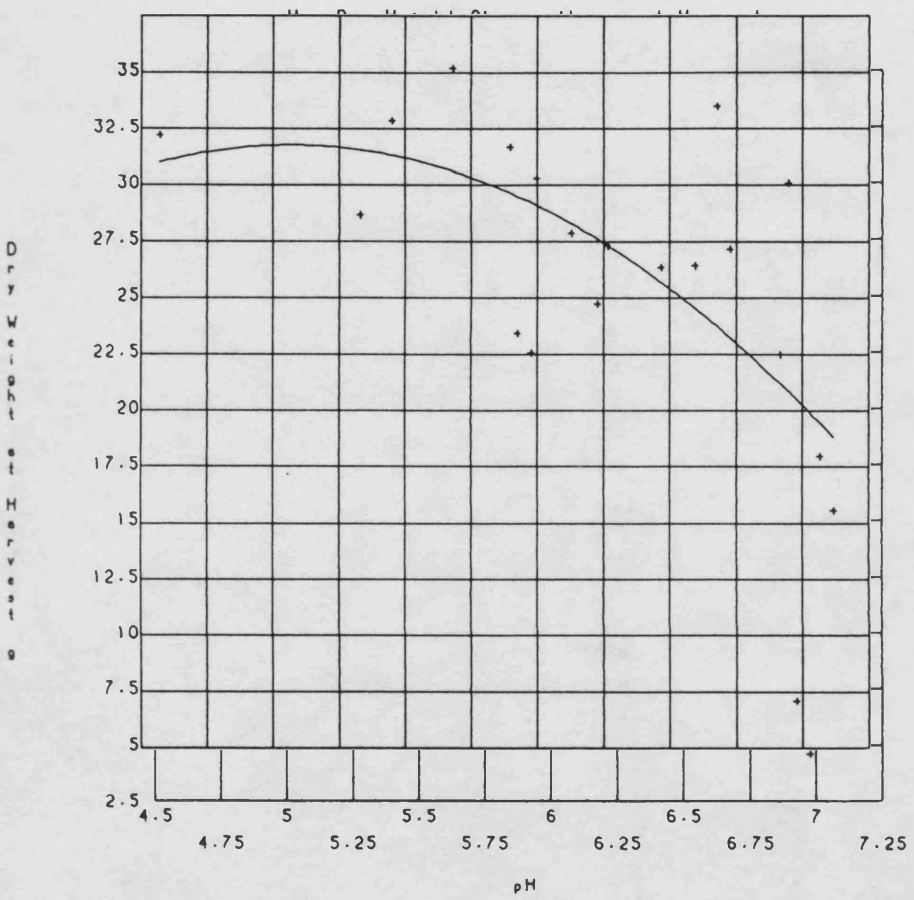
correlations in combination with bulk density. Overall correlations between these medium parameters and dry weight of chrysanthemum at harvest were poor. In addition bulk density was found to be highly (P=0.001) correlated to pH which means that the correlation between bulk density and dry weight at harvest may be purely incidental. Verlodt et al (1985) and Waller and Wilson (1984) were unable to link physical properties to growth, but pH has been found to have a significant influence over growth in that it modifies nutrient uptake (Bunt 1976).

Dry Weight of Pinchings

Parameter	r^2%	Significance level	df
pH	11.6	-	16
us/cm	55.6	***	16
BD	0.0	-	16
$(pH)^2$	-4.9	-	16
$(us/cm)^2$	43.4	**	16
pH+us/cm	66.5	***	15
$(pH)^2+(us/cm)^2$	47.2	**	15
pH+BD	18.5	-	15
$(pH)^2$+BD	10.8	-	12
us/cm+BD	54.0	**	15
$(us/cm)^2$+BD	47.6	**	12
pH+us/cm+BD	73.3	***	14
$(pH)^2+(us/cm)^2$ BD	73.0	***	11

In the case of dry weight of pinchings the use of $(pH)^2$ and $(us/cm)^2$ did not improve any of the correlations over pH or us/cm. In this case conductivity was most influential over growth, being negatively correlated at the P=0.001 level. The inclusion of pH and bulk density into the equation improved the correlation. The quadratic relationship for conductivity vs dry weight of pinchings can be

seen in fig. 3.20. The tailing off towards the higher conductivity level is probably explained by the curve approaching the initial weight of the cuttings i.e. no, or little growth occurred at the excessively high conductivity found in the most saline media. The curve is linear for most of its path which would explain the better linear correlation between conductivity and dry weight of pinchings than between $(us/cm)^2$ and dry weight of pinchings. The analytical techniques appear to predict growth of young chrysanthemum plants reasonably well, but the relationships become weaker as the plants get older. This is to be expected since the media properties change with time and the plants adapt to their environment e.g. they are able to adjust their cell osmotic pressure to compensate for high medium salinity (Stewart and Ahmed 1983).



Relationship Between pH and Chrysanthemum Dry Weight at Harvest.

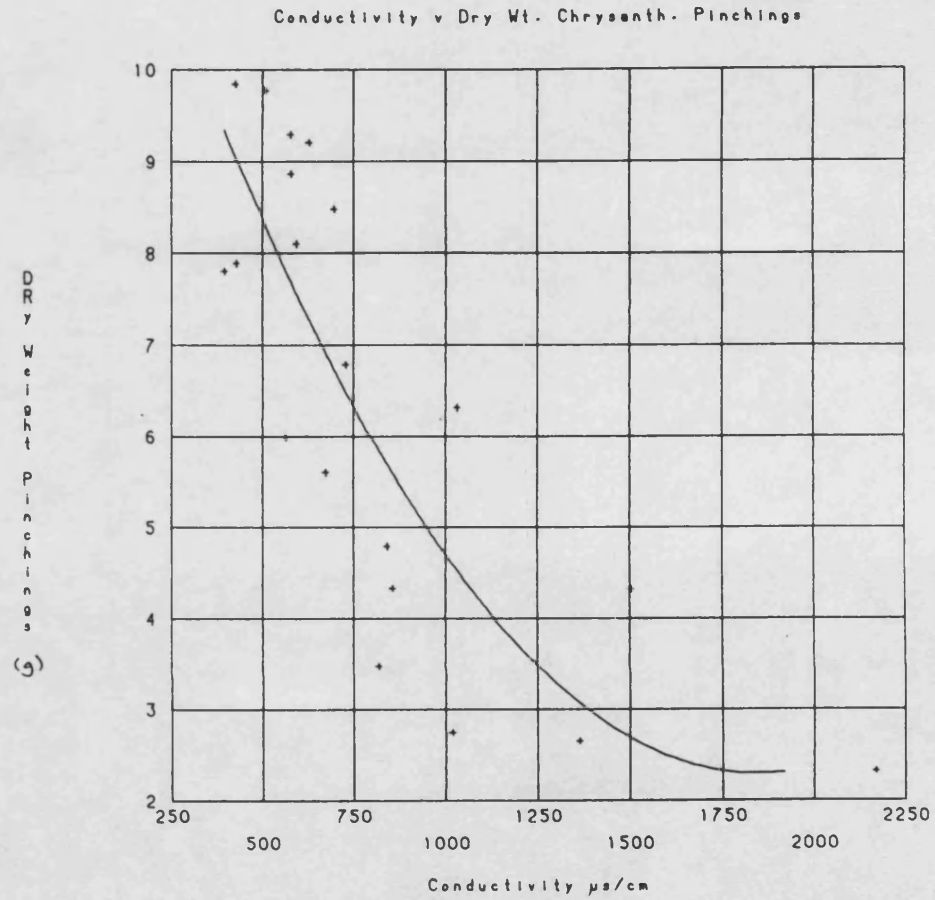


Fig. 3.20

Relationship Between Conductivity and Dry Weight of Chrysanthemum Pinchings.

Nursery Stock Trial.

A nursery stock growing trial was set up in April 1985 to compare physically and chemically amended growing media.

Materials and Methods

Species	Date Potted
Spiraea 'Grefsheim'	5/4/85
Hypericum 'Hidcote'	11/4/85
Santolina incana	15/4/85
Senecio greyi	16/4/85
Rubus 'Tricolor'	17/4/85

Rooted one year old cuttings were potted into 1 litre black polythene bags containing the following growth media treatments, with 1 plant/bag, 3 bags/plot and 3 plots/medium.

Control (CON)

3:1 Sphagnum peat: coarse sand (Stockwell RBL Brand).

Plus:-

Kg/m^3 peat	
4.5	Ficote 14:14:14
0.75	Single superphosphate
2.4	Magnesian limestone
-	Ground limestone
0.3	Frit WM 253A

Physical and chemical amendments were made to the following media as estimated from analyses:-

Worm-worked Cow Slurry (C)

C1 100% C + 1/4 rate Ficote + 2Kg/m^3 magnesian limestone.

C2 1:2:1 C:peat:coarse sand + 3/4 rate Ficote + 2Kg/m^3 magnesian limestone.

C3 2:1:1 C:peat:coarse sand + 1/2 rate Ficote + 2Kg/m^3 magnesian limestone.

Worm-worked Pig Slurry (P)

P1 100% P + 1/4 rate Ficote + 1.4Kg/m^3 ground limestone.

P2 1:2:1 P:peat:coarse sand + 3/4 rate Ficote + 1.8 Kg/m^3 magnesian limestone + 500g/m^3 ground limestone.

P3 2:1:1 P:peat:coarse sand + 1/2 rate Ficote + 1.2 Kg/m^3 magnesian limestone + 650g/m^3 ground limestone.

Bark (B) (Cambark Fine)

B1 100% B + full rate of all fertilizer as for control.

B2 3:7 B:peat + full rate of fertilizer.

B3 1:2:1 B:peat:coarse sand + full rate of fertilizer.

Spent Mushroom Compost (M)

M1 100% M (no added fertilizer).

M2 1:2:1 M:peat:coarse sand + 1/2 rate Ficote.

M3 1:2:1 M:peat:perlite + 1/2 rate Ficote.

Leafmould (Lf)

Lf1 100% Lf + full rate Ficote + 0.75Kg/m^3 superphosphate + 2.0Kg/m^3 magnesian limestone.

Lf2 3:1 Lf:peat + full rate Ficote + 0.75Kg/m^3 superphosphate + 2.0Kg/m^3 magnesian limestone.

Lf3 1:1 Lf:peat + full rate Ficote + 0.75kg/m^3 superphosphate + 2.0Kg/m^3 magnesian limestone.

Doncaster sewage/refuse compost (D)

D1 100% D + 0.5 rate Ficote + 500g/m^3 magnesian limestone.

D2 1:1:1 D:peat:perlite + 5/6 rate Ficote + 2.0Kg/m^3 magnesian limestone.

D3 2:1:1 D:peat:perlite + 3/4 rate Ficote + 1.5Kg/m^3 magnesian limestone.

For those mixtures containing coarse sand the fertilizer rates were based on the volume of organic compost + peat . It was assumed that the sand would be absorbed completely in terms of volume as in 3:1 peat:sand mixtures i.e. $3m^3$ peat + $1m^3$ sand -> $3m^3$ mixture. There are certain problems in making such assumptions when different composts are involved, since the extent to which the particles of two media fit together will depend on the particle size distributions of both constituents, and no determination of this property has been made in this study. However, the percentage error between assumed volume on addition of sand and actual volume was found to be small for all media. Perlite was assumed to be additive in terms of volume. In fact a slight reduction in expected volume occurred in each case.

The potted plants were placed on a drained sand bed (Efford design (8)) according to the plan (fig.

3.21). All species were laid out using the same experimental design. The bags were moved every 2 weeks to prevent rooting through and all weeds removed.

The following recordings were made:-

Damage Report

A general report on the condition of the plants was made at periodic intervals.

Rubus Stem Length

The total length of stems per plant was recorded on 25/7/85.

Harvest

All species except Rubus were cut at soil level and dry weights recorded. Rubus plants were retained for harvesting in May 1986, to assess growth media over a longer period. Unfortunately frost damage during the winter of 1985/86 resulted in the loss of most of this experiment before it could be harvested.

Species	Harvest Date
Spiraea	10/7/85
Hypericum	22/8/85
Santolina	26/8/85
Senecio	5/9/85

Block 1	Block2	Block3	
GGG	GGG	GGG	
Lf1	M3	D1	
C1	P3	P2	
P1	Lf1	Lf1	
M3	Lf2	C3	
P2	D3	D3	
P3	CON	P3	
M1	Lf3	B1	
B1	C2	C1	N
Lf3	C1	M3	<-----
CON	P1	Lf2	
D1	C3	B2	
D3	B2	P1	G=Guard
M2	M1	Lf3	
B2	M2	M1	
B3	P2	C2	
C3	D1	B3	
C2	B1	D2	
Lf2	D2	M2	
D2	B3	CON	
GGG	GGG	GGG	

Plan of Nursery Stock Trial. Fig. 3.21

Nursery Stock Trial Results and Discussion.

Table 3.11 gives the physical and physicochemical properties of the nursery stock media. NB These media contained the slow release fertilizer Ficote and therefore the pH and conductivity measurements will be affected by the release of nutrients in the extraction solution from the fertilizer granules, which would not be released so rapidly in the medium under normal conditions.

The ANOVA results for growth of the different species can be seen in figure 3.22.

Rubus Stem Length

df	38
LSD 0.05	570.2
LSD 0.01	767.9
LSD 0.001	1018.0
f-ratio	4.08***
n	3

C1, D3, B1 (P=0.05), P3, P1, M3, D2 (P=0.01), D1 and M1 (P=0.001) all produced plants with significantly shorter stems than the control.

One plant out of the nine replicates died in each of the following treatments:- Lf2, P3, D3, P1, D1 and two plants died in M1. Rubus stem length was found to be highly correlated to both pH and conductivity (P=0.001), pH being more highly correlated than conductivity (us/cm). However, high salinity (conductivity) was regarded as the most likely cause of plant death since Rubus tricolor is known to be tolerant of a wide range of soil pH (76).

Conductivity and pH were significantly correlated to each other (P=0.001). Conductivity was probably

MEDIUM		DRY BULK DENSITY g/l	SATURATED BULK DENSITY g/l	BULK DENSITY CONTAINER CAPACITY g/l	WATER CONTENT SATURATION cm^3	WATER CONTENT CONTAINER CAPACITY cm^3	AIR SPACE CONTAINER CAPACITY cm^3	VOL. % AIR AT CONTAINER CAPACITY	FIBSPAN BULK DENSITY mg/l	pH	us/cm
Doncaster	1	483.6	1196.9	1107.0	731.3	623.4	89.9	8.99	-	-	-
Compost	2	247.0	994.2	834.4	747.2	587.4	159.8	15.98	205.2	5.57	888
	3	286.5	1034.8	904.9	748.3	618.4	129.9	12.99	237.9	5.67	953
Cambark	1	180.8	911.6	586.4	730.8	405.6	325.2	32.52	-	-	-
Fine	2	140.0	916.1	838.3	776.1	698.3	77.8	7.78	111.9	4.45	523
	3	515.4	1193.9	1144.8	678.5	629.4	51.1	5.11	418.9	4.30	405
Spent	1	288.5	1052.2	987.9	763.7	699.4	64.3	6.43	-	-	-
Mushroom	2	537.5	1263.6	1238.6	726.1	701.1	25.0	2.50	395.4	5.92	1068
Compost	3	143.5	916.1	819.9	772.6	676.4	96.2	9.62	120.2	5.80	1018
Leafmould	1	395.2	1028.4	1181.6	813.2	786.4	26.8	2.68	-	-	-
	2	298.8	1088.0	1020.0	789.2	721.2	68.0	6.80	-	-	-
	3	219.3	1041.3	973.1	822.0	753.8	68.2	6.82	184.4	5.18	1058
WW Pig	1	236.1	1065.1	995.3	829.0	759.2	69.8	6.98	219.1	6.38	1750
Slurry	2	527.9	1227.6	1194.8	699.7	666.9	32.8	3.28	439.4	5.10	796
	3	538.2	1285.9	1253.1	747.7	714.9	32.8	3.28	430.8	5.92	1160
WW Cow	1	135.3	1048.2	1021.3	912.9	866.0	26.9	2.69	-	-	-
Slurry	2	526.7	1219.1	1186.4	692.4	659.7	32.7	3.27	366.2	4.10	611
	3	547.1	1287.4	1256.9	740.3	709.8	30.5	3.05	390.5	5.23	1067
Control		445.2	1165.4	1131.2	720.2	686.0	34.2	3.42	358.7	3.83	387

Nursery Stock Media Analyses Table 3.11

most influential over growth as stated above and the correlation with pH incidental (see fig. 3.23).

Volume percent air space and water holding capacity (at container capacity) were not significantly correlated to stem length, although they were significantly correlated (P=0.01) to each other.

Nursery Stock Dry Weight

Dry weight was determined for Santolina , Spiraea , Hypericum and Senecio . The ANOVA results can be seen below and in figure 3.22.

	Santolina	Hypericum	Spiraea	Senecio
df	38	38	38	38
LSD 0.05	10.09	9.69	9.42	20.82
LSD 0.01	13.58	13.05	12.68	28.04
LSD 0.001	18.01	17.31	16.81	37.18
f-ratio	6.28***	2.96**	4.72***	2.54**
n	3	3	3	3

Santolina

D1 (P=0.05), B1, D3, C1 (P=0.01) and M1 (P=0.001) gave significantly lighter plants than the control. The other treatments were not significantly different from the control. No visible differences between the treatments were observed during the experimental period.

Hypericum

C1, P1 (P=0.05) and M1 (P=0.01) were significantly lower in dry weight than the control; the other treatments were not significantly different.

Spiraea

D1, B1 (P=0.05), C1 (P=0.01) and M1 (P=0.001) were significantly lower than the control; the other

treatments were not significantly different.

Senecio

C1, D1 and M1 (P=0.05) were significantly lower in dry weight than the contol; the other treatments were not significantly different to the control.

General Results

Similarities are evident between the five nursery stock species with respect to growth in the different media. the media without physical amendments (treatment 1) gave consistently lower dry weights than the control (excepting Lf1).

C1, D1 and M1 were significantly lower in dry weight in most cases. Overall, though, the differences were not great between the amended treatments; B3, Lf3, P3, P2, Lf2 and B2 registering highly in each case with respect to dry weight. This shows that the attempt to produce media of roughly equal ability to support nursery stock growth, based on medium analyses, was successful.

The photographs show the difference in size between the best and worst treatments for Spiraea (P2 and M1)(photographs 3.11 and 3.12), and the effect of physical amendment on bark media (B1 and B3) and growth of Rubus (photographs 3.13 and 3.14). The improvement in growth is presumably attributable to increased water and nutrient retention in B3 (see table 3.11).

Rubus Stem Length (mm)

1696	1345	1332	1194	1146	1135	1093	1015	939	815	755	711	616	561	556	548	524	306	109
Lf3	CON	B3	Lf2	B2	C2	P2	Lf1	C3	M2	C1	B1	D3	P3	M3	P1	D2	D1	M1

Santolina Dry Weight (g)

70.0	69.6	67.0	66.7	65.1	64.2	62.9	62.5	62.4	61.8	61.0	58.4	55.2	55.1	50.4	46.6	46.0	44.7	42.1
B3	P3	C2	Lf3	P2	M2	M3	D2	B2	Lf2	CON	Lf1	C3	P1	D1	B1	D3	C1	M1

Senecio Dry Weight (g)

82.3	80.0	76.1	74.9	74.7	73.8	73.7	72.1	70.1	69.0	68.5	68.2	67.5	65.1	61.9	49.8	46.8	45.9	45.7
B2	P2	Lf2	P3	C2	B3	Lf3	M2	M3	C3	CON	D3	D2	Lf1	B1	P1	C1	D1	M1

Hypericum Dry Weight (g)

35.7	35.1	34.7	34.4	34.4	34.4	33.2	32.3	31.2	30.6	30.1	30.0	29.6	29.0	26.1	22.9	19.8	19.6	16.9
P2	Lf2	B3	P3	Lf3	C3	M3	B2	D2	Lf1	CON	M2	C2	B1	D3	D1	C1	P1	M1

Spiraea Dry Weight (g)

39.8	38.0	37.5	36.3	36.0	35.3	34.7	34.2	33.5	32.8	30.9	29.5	29.3	25.0	24.0	22.1	21.7	18.6	15.9
P2	Lf1	B2	Lf3	C3	B3	Lf2	M3	C2	CON	P3	D2	M2	D3	P1	D1	B1	C1	M1

NURSERY STOCK ANOVA RESULTS FIG. 3.22

Photo.3.11 Spiraea 'Grefsheim'
Best treatment P2.

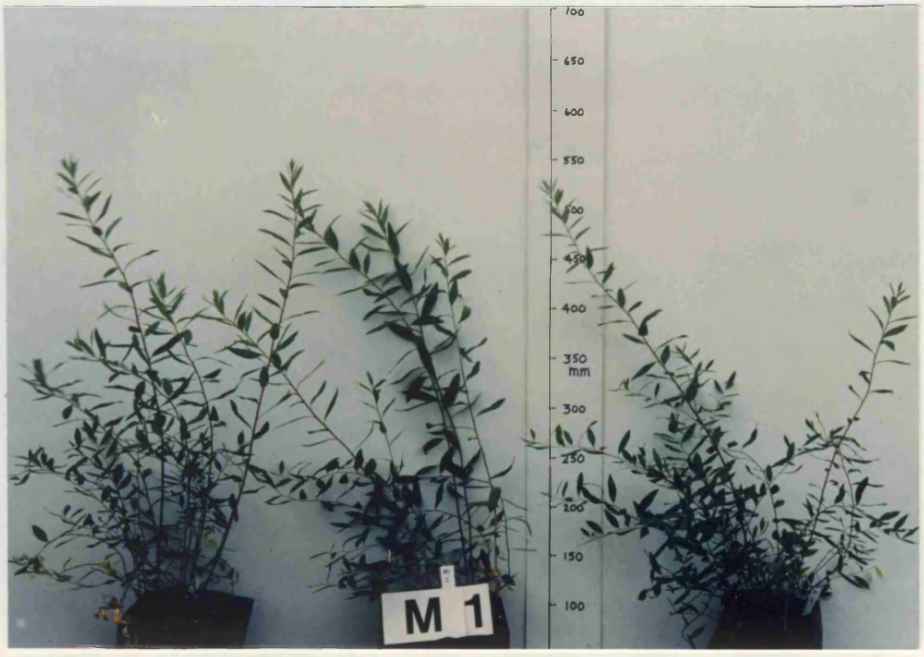


Photo.3.12 Spiraea 'Grefsheim'
Worst treatment M1.

Photo.3.13 100% Bark.

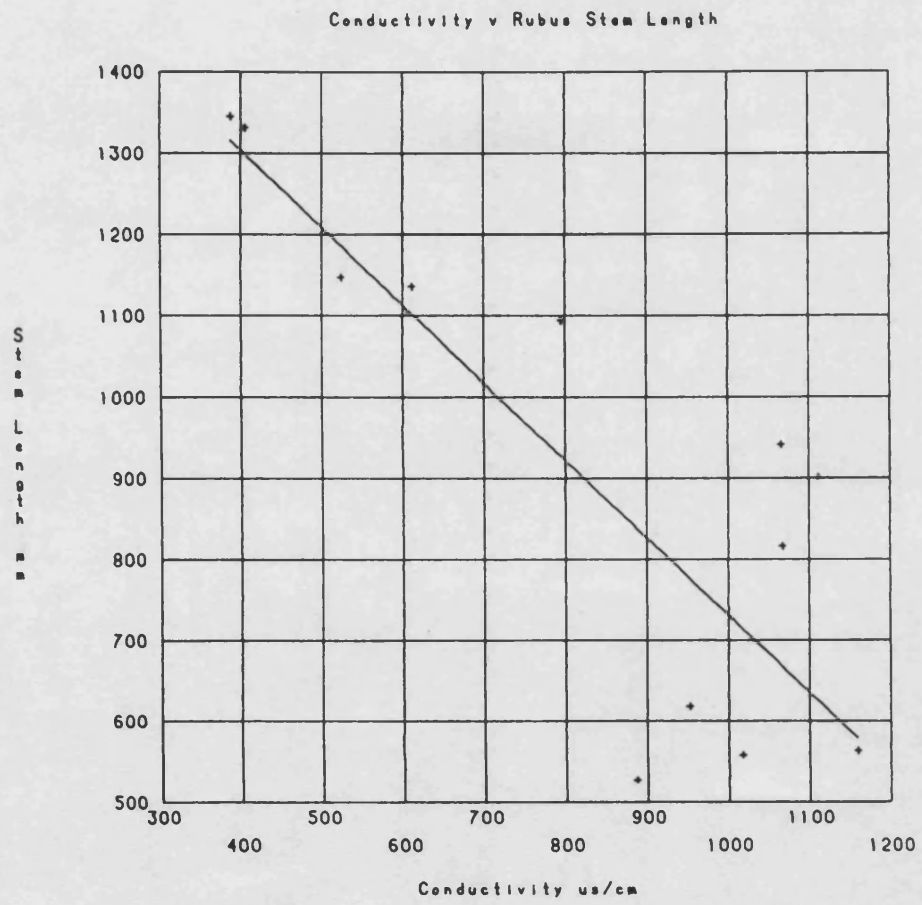
Photo.3.14 1:2:1 B:peat:coarse sand.

The Effect of Physical Amendment on Growth of Rubus 'Tricolor' in Bark Media.

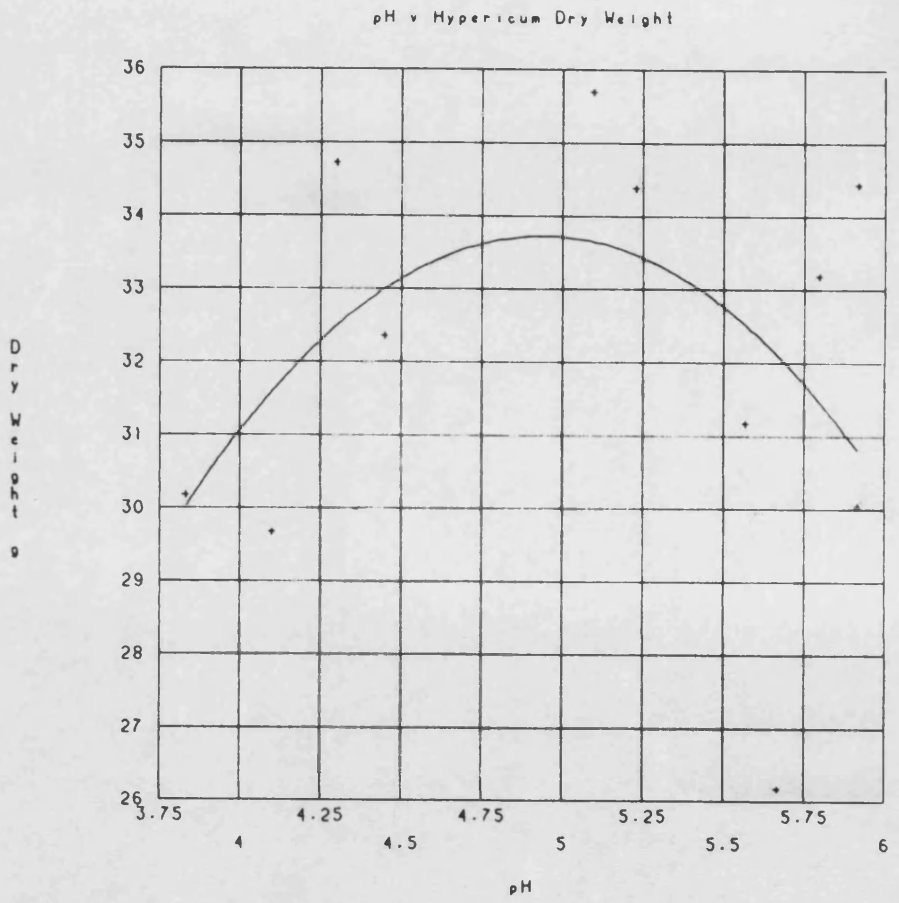
Evaluation of Analytical Techniques

Dry weight of all four species was correlated to pH, conductivity, water holding capacity (at container capacity) and volume percent air space. No significant correlations were found at all. The curplot program gave quadratic relationships as the best fit for dry weight vs pH for all species (see fig. 3.23 for example). $(pH)^2$ was therefore correlated to dry weight, but again no significant correlation was found. The only significant correlations found for nursery stock were those for rubus mentioned above. The reason for this may be that the attempt to make the media similar in ability to support nursery stock growth was so successful that insufficient extremes of media conditions existed to allow significant correlations to show up. In addition, the inclusion of a slow release fertilizer in the media may have affected the pH and conductivity measurements in such a way as to cause them to bear a poorer relationship to actual conditions in the media than that present for media without a slow release fertilizer. Also, the properties of the media at harvest may have correlated better with the plant growth than the initial properties.

The absence of significant correlations between dry weight or stem length and physical properties of the media is not surprising in view of the results of the other experiments presented here and the results of Waller and Wilson (1984) and Verlodt (1985).



Relationship Between Conductivity and Rubus Stem Length.



Relationship Between pH and Hypericum Dry Weight.

Fig. 3.23

CHAPTER 4

Shrinkage Experiment

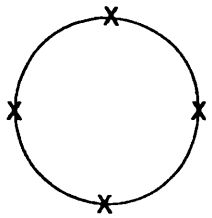
An experiment was set up to determine the percentage volume loss of media over the period of a year. The media formulated for the nursery stock trial were used for this experiment since they included both amended and unamended composts. In addition, shrinkage of the medium becomes more important the longer term the crop i.e. more important for nursery stock plants than for relatively short term crops e.g. glasshouse pot plants.

Shrinkage of the medium is undesirable in that:

1. It reduces the total volume of medium into which the roots can extend, thus limiting growth.
2. It may result in the movement of the medium away from the sides of the pot, allowing water to be channelled around the medium rather than through it.
3. It may lead to compaction of the medium through break down of particles thus reducing aeration.
4. It may give reduction in stability of the potted plant through actual mass loss of the medium resulting from breakdown and oxidation of organic matter.

The experiment was set up in May of 1985 to the same design as the nursery stock trials, with three blocks and 3 pots per replicate. 11cm pots were filled loosely with medium, knocked on the bench once then struck off level. A wooden disc was used to compress the surface to 0.75cm from the rim. Pots were laid out on a sand bed and watered well. They were watered thereafter at the same time as the nursery stock trials.

The loss in volume was determined monthly by measuring the distance from the rim of the pot to the medium at four places, and a mean depth calculated (m).

e.g. 

Weeds were removed each measuring day.

The percentage volume loss (PVL) was calculated with the aid of a simple computer programme based on the following equations, where the volume of a pot and sections of a pot are described in terms of sections of a cone (see fig. 4.1):-

1. Percentage Volume Loss (PVL)

$$PVL = \frac{Vp-Vs}{Vp} \times \frac{100}{1}$$

Where Vp = Volume of pot

and Vs = Volume of section of cone.

2. Volume of Pot (Vp)

$$Vp = Vwc - Vsc$$

Where Vwc = Volume of whole cone

and Vsc = Volume of small cone.

3. Volume of Whole Cone (Vwc)

$$Vwc = \frac{1}{12}\pi Dt^2 \left[\frac{Dt \left(l^2 - \left(\frac{Dt-Db}{2} \right)^2 \right)^{\frac{1}{2}}}{(Dt-Db)} \right]$$

Volume of Small Cone (Vsc)

$$Vsc = \frac{1}{12}\pi Db^2 \left[\frac{Db \left(l^2 - \left(\frac{Dt-Db}{2} \right)^2 \right)^{\frac{1}{2}}}{(Dt-Db)} \right]$$

and Volume of Section of Cone (Vs)

$$Vs = Vwc - \frac{1}{12}\pi D^2 \left[\frac{D \left(l^2 - \left(\frac{Dt-D}{2} \right)^2 \right)^{\frac{1}{2}}}{(Dt-Db)} \right]$$

Where Dt = Diameter of top of pot
Db = Diam. of base of pot
l = Length of side of pot
and D = Diam. of surface of medium.

4. Diameter of surface of medium (D)

$$D = Dt - \frac{m(Dt-Db)}{l}$$

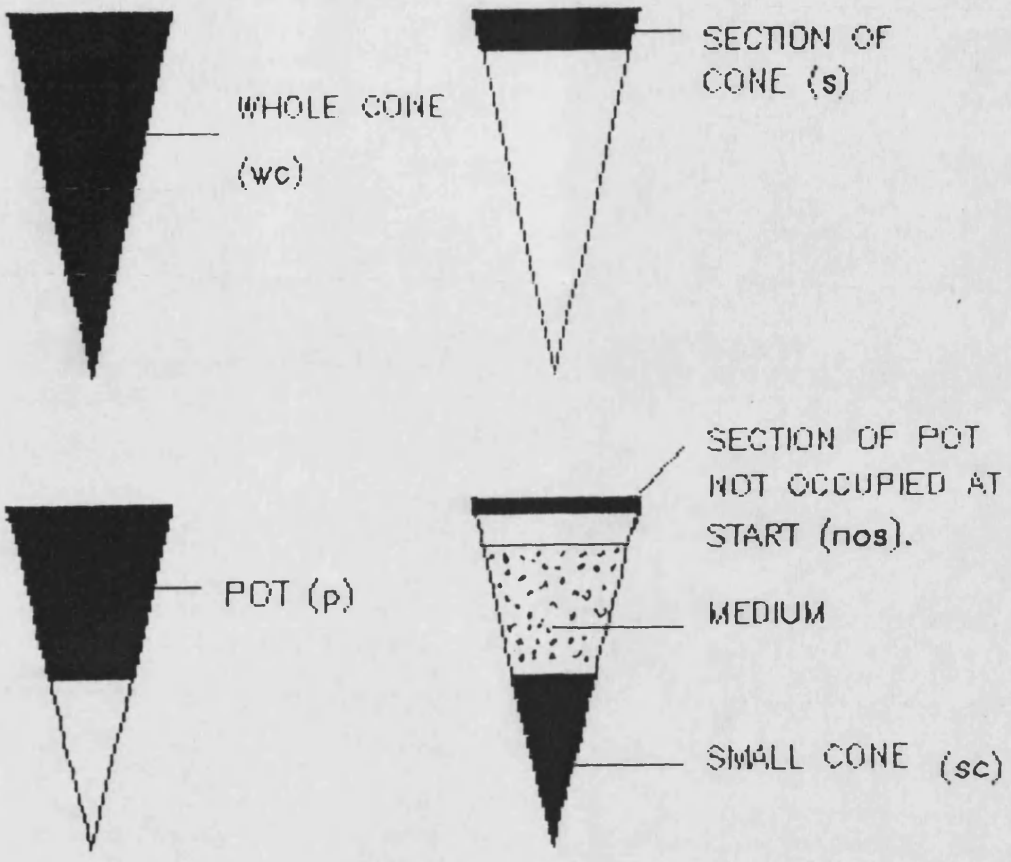
Where m = mean depth of medium from rim of pot.

In this experiment the inclusion of an extra term to take into account the volume of the pot not occupied by medium at the start was required (because of compression of the medium to 0.75cm from the rim).

5. Volume not occupied at start (Vnos)

Vnos is calculated as for Vs and is subtracted from Vp and Vs before calculation of PVL.

Results can be seen in figs. 4.2 to 4.3c.



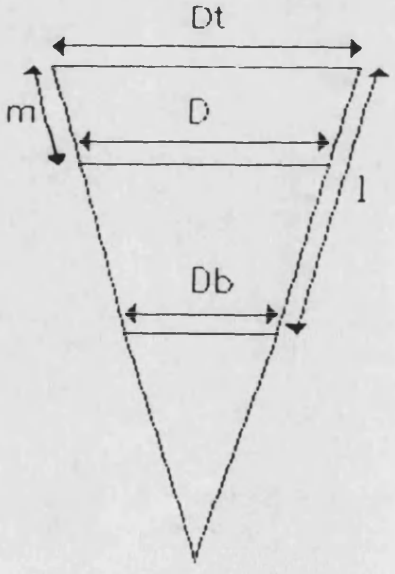


Fig. 4.1 Shrinkage Experiment. Sections of a Pot Described in Terms of Sections of a Cone.

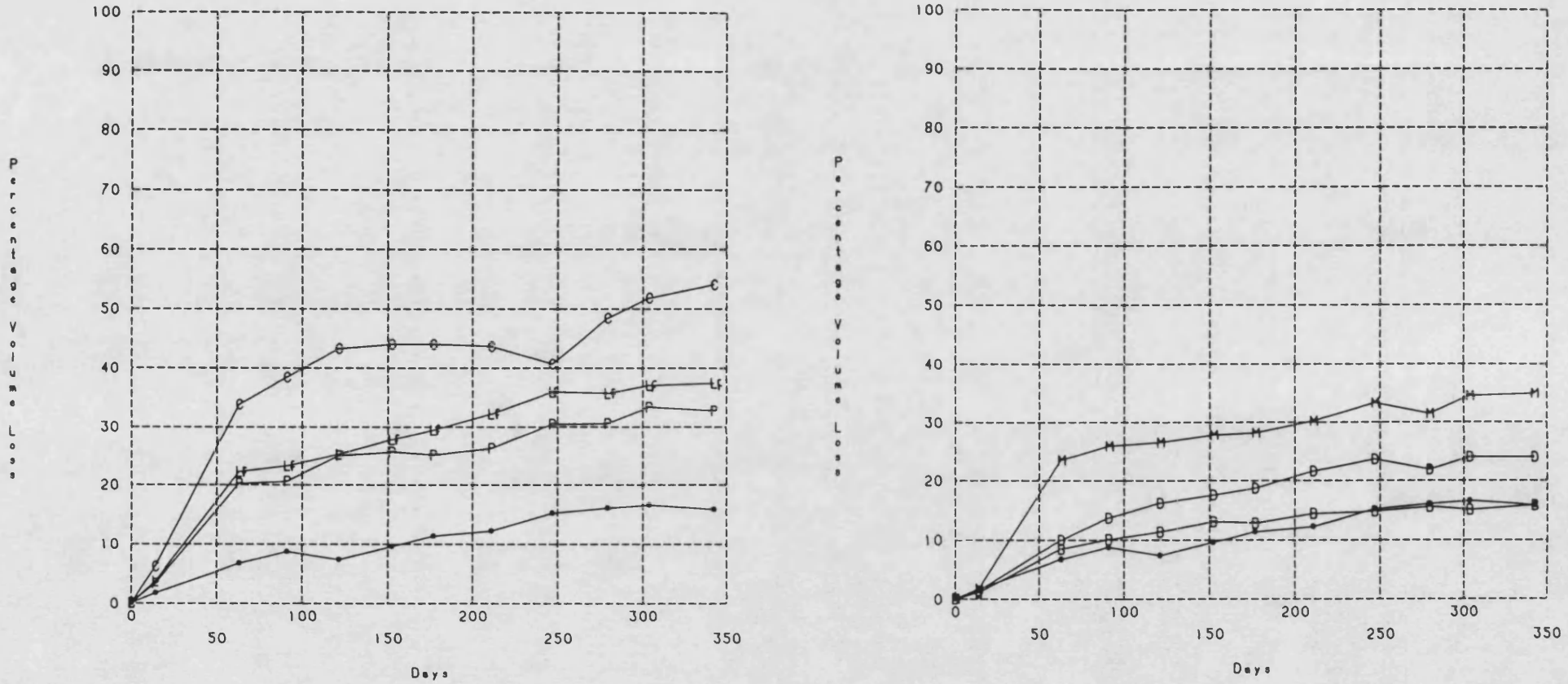


Fig. 4.2 Shrinkage with Time - Unamended Media Compared to Control *.

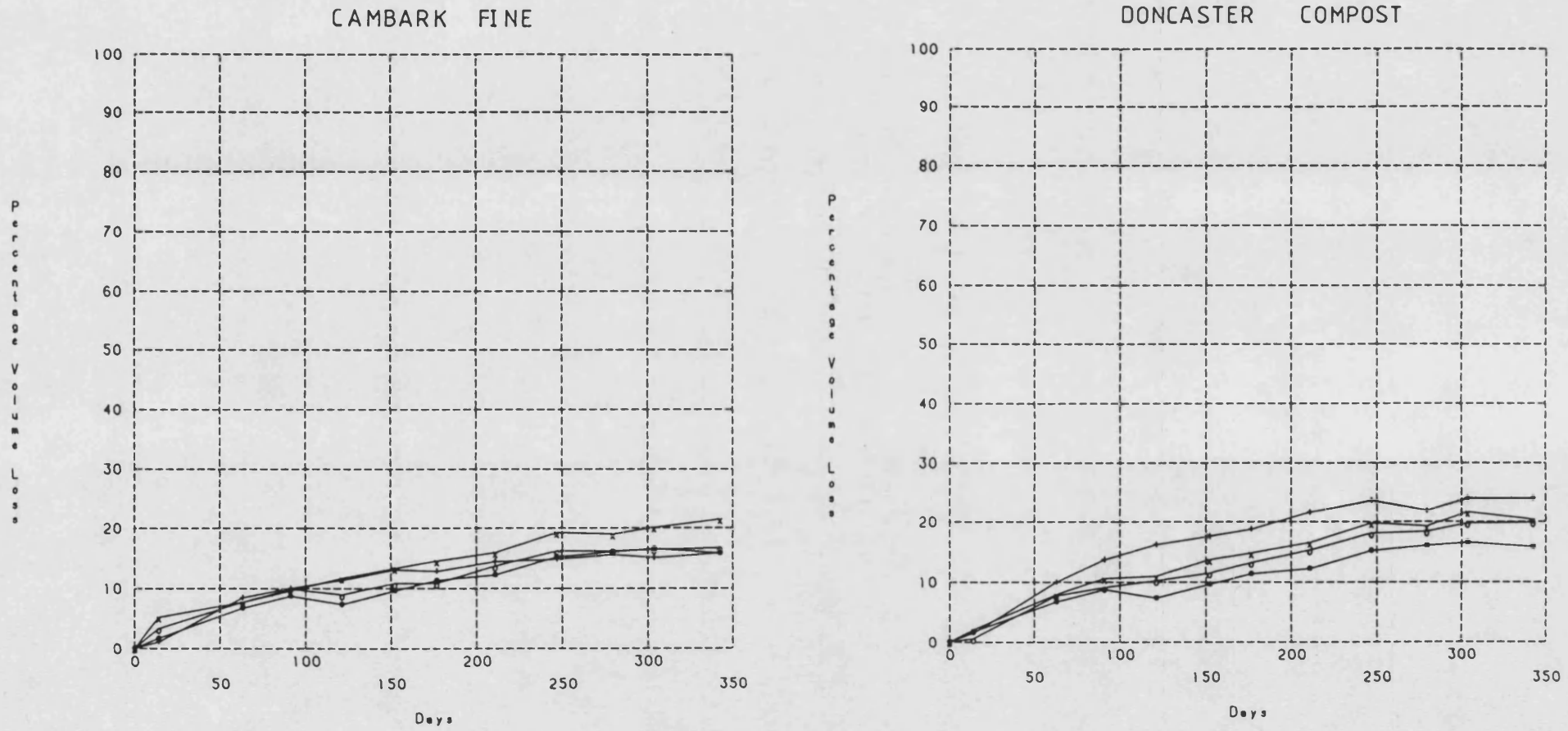


Fig. 4.3a Shrinkage with Time. Amended and Unamended Media Compared to Control *.

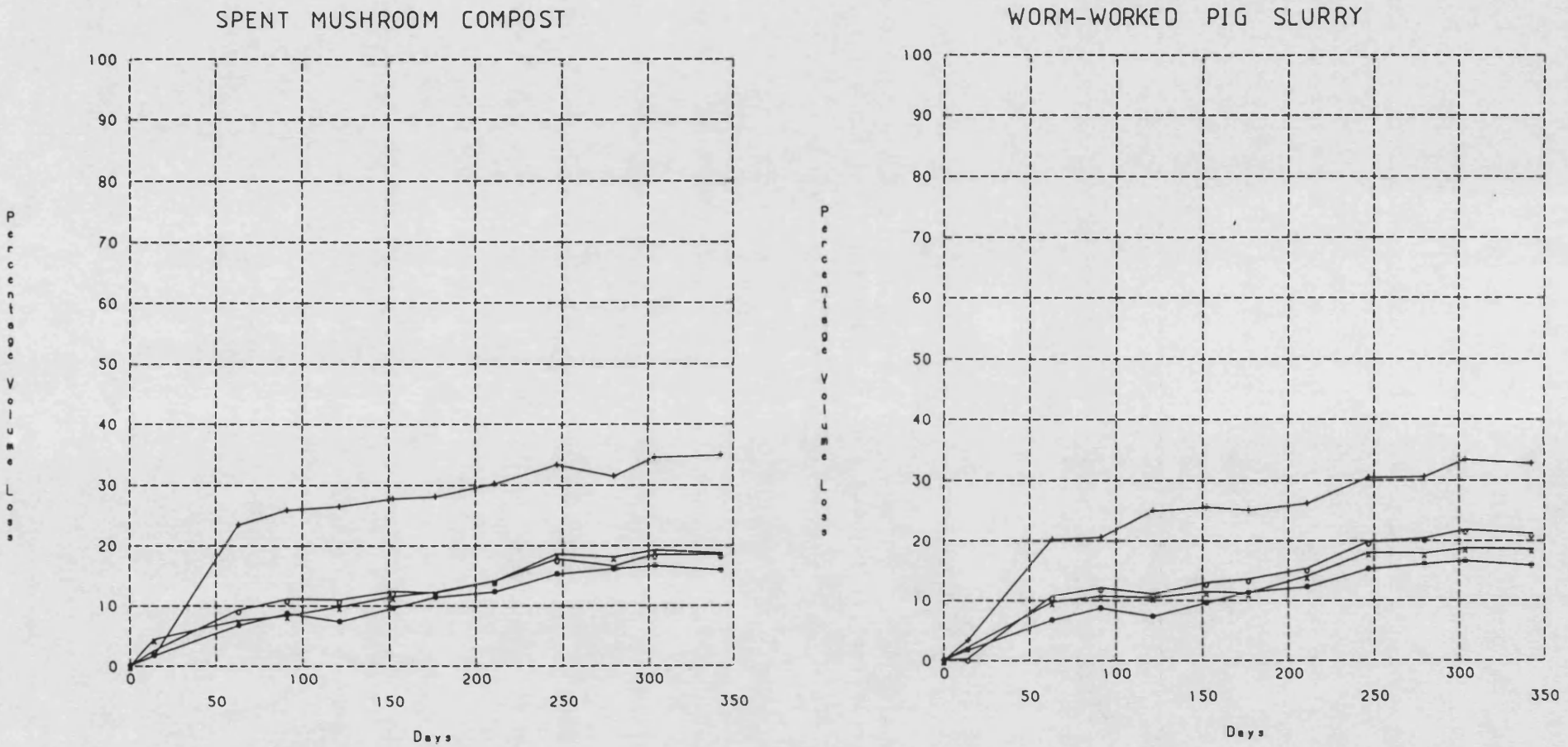


Fig. 4.3b Shrinkage with Time. Amended and Unamended Media Compared to Control *.

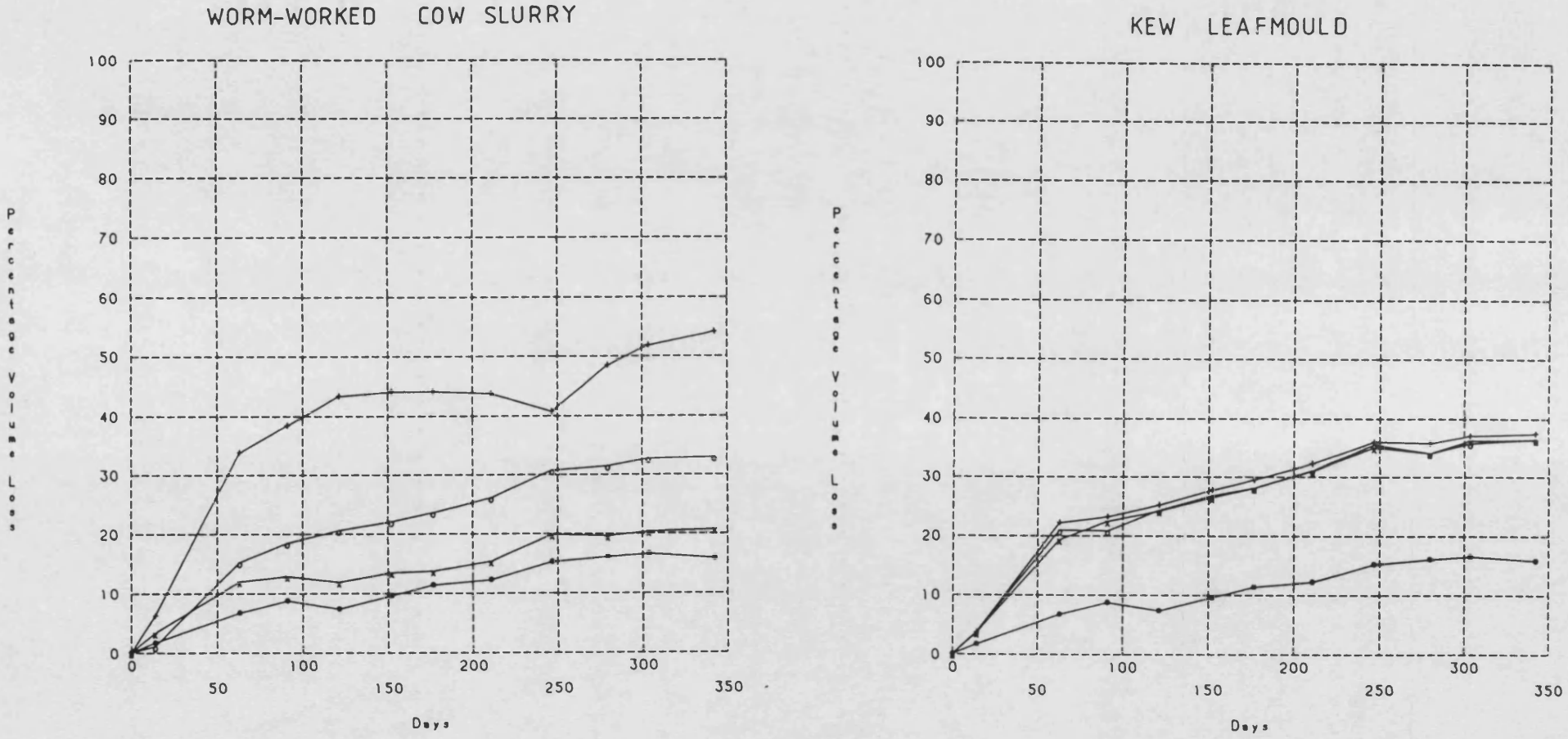


Fig. 4.3c Shrinkage with Time. Amended and Unamended Media Compared to Control *.

Shrinkage Experiment Results and Discussion

Figure 4.2 shows the shrinkage with time of the unamended treatments (treatment 1) compared to the control medium. The media were divided into two groups for reasons of clarity.

KEY:
- C worm-worked cow slurry
- P work-worked pig slurry
- Lf Kew leafmould (3 years old)
- M spent mushroom compost (2 years old)
- D Doncaster sewage/refuse compost
- B Cambark Fine
- * Control (3:1 sphagnum peat:sand)

Worm-worked cow slurry had the greatest volume loss over time, with less than 50% of the initial volume remaining after 343 days (end of experiment).

M, Lf and P had similar patterns of shrinkage and loss of volume to each other by the end of the experiment, P with a final volume loss of 33%, M with 35% and Lf with 37%. Lemaire et al (1985) reported a volume loss of 42% for spent mushroom compost after 6 months; their compost possibly being less decomposed at the start than that used here.

Doncaster compost lost volume at a slightly greater rate than the control, 76% of the initial volume remaining at day 343, whilst the loss of volume of B was similar to the control, both ending with a loss of 16% (84% remaining).

None of these results are surprising. As predicted (page 79) the shrinkage of C was far greater than that of P, the difference being due to the greater break down of fibre in the slurry of the ruminant cattle than in that of the non-ruminant pig. The shrinkage pattern of leafmould would depend on its age and degree of decomposition at the start. This

leafmould was two years old when used, and obviously quite a substantial amount of shrinkage (decomposition) occurred over the next year.

At times (e.g day 247 for C) the media appeared to gain volume. This can be explained by the condition of the medium when it was measured i.e. whether wet, dry or frozen. Below is a summary of the temperature ranges recorded over the preceding month and the condition of the media on the day of measuring. In general wet, moist or freezing conditions caused slight swelling of most of the media.

Day	Month (end of)	Temperature (°C) max.	min.	Condition
14	June	32	-1	Dry
63	July	33	4	Dry
91	Aug.	31	9	Dry
121	Sept.	31	-1	Wet
152	Oct.	?	?	Moist
177	Nov.	30	-9	Wet
211	Dec.	3	-14	Wet
247	Jan.	9	-11	Slightly frozen
280	Feb.	?	?	Frozen solid
304	Mar.	17	-12	Moist
343	Apr.	29	-4	Dry

A proportion of the shrinkage must be accounted for by the settling of particles in the pot. The extent to which this occurred could have been estimated by a measure of bulk density before and after the experiment. Regulski (1984) found that breakdown of particles caused most shrinkage in bark, but that settling of particles was primarily responsible for shrinkage in a gasifier residue. The control medium shrank little over the 343 days of the experiment,

most of the shrinkage probably due to settling rather than decomposition. C on the other hand probably lost most of its volume through decomposition and in solution via drainage. The greatest rate of shrinkage occurred during the first 60-70 days of the experiment, followed by a gradual decrease in volume. Lemaire et al (1985) found that most shrinkage occurred during the first 6 months. The data presented here suggests that the shrinkage continues at a steady rate for a longer period than this (after the initial rapid shrinkage phase).

Figures 4.3a to 4.3c give the shrinkage curves for the individual media types compared to the control.

KEY: * Control
+ Treatment 1 - unamended
x Treatment 2 - amended
o Treatment 3 - amended

The list of amendments are presented under the Nursery Stock section (p140).

Bark

The shrinkage of bark treatments were very similar to the control. The treatment containing the most peat (B2) lost the most volume suggesting that the shrinkage of peat was greater than that of bark. Lemaire et al (1985) found that pine bark lost 11% of its volume over 6 months, and sphagnum peat lost 20%.

Doncaster Compost

The addition of perlite reduced the shrinkage of this medium. Shrinkage by day 343 was not, however, greatly different to the control for any of the D treatments.

Worm-Worked Pig Slurry

The amendments were successful in reducing the shrinkage of P to levels close to that of the control. The shrinkage of P being, apparently, not too dissimilar to that of sphagnum peat when in combination with coarse sand (P2=P:peat:sand 1:2:1 and P3=P:peat: sand 2:1:1).

Spent Mushroom Compost

Again the amendments were successful in reducing the shrinkage to the control level. Coarse sand and perlite were apparently equally resistant to shrinkage, since both M2 and M3 had similar patterns of shrinkage. The shrinkage of M1 was also apparently not too dissimilar to that of sphagnum peat.

Leafmould

Only sphagnum peat was substituted for leafmould in treatments 2 and 3. It appears that both sphagnum peat and leafmould had similar shrinkage patterns.

Worm-Worked Cow Slurry

The shrinkage of C was obviously far greater than that of sphagnum peat (C2=1:2:1 C:SP:sand and C3=2:1:1 C:SP:sand). C2 shrank the least and would have been an acceptable alternative to the control, but it contained the least C (25%).

CHAPTER 5

Seedling and Transplant Trials

Seedling and transplant trials were performed in an attempt to develop a rapid growth test which could predict suitability of a medium as a potting compost. The majority of the work involved the selection of species, planting densities, and other test parameters. Test species were then compared with each other for growth response to the different composts and with growth of the large scale growth trial species. A general test method was followed, as outlined below, with slight alterations dependent on the purpose of the test.

Seedling Trials- General Method.

Equipment:- 1. 6.5 x 6.5cm vacopots.
2. Seed
3. Medium

Pots were loose filled with medium, banged on the bench twice and levelled with a straight edge. The medium was then compressed to 0.5cm below the rim of the pot with even pressure to give a level surface. Seed was sown, g/pot (dependent on seed type) with 3 pots per treatment. A thin layer of the same medium was sprinkled over the top to just cover the seed using a 0.75cm sieve. The pots were arranged in a randomised block design (3 blocks) on a greenhouse bench at 20°C day and 13°C night, and watered daily as required. Seedlings were harvested after 11 days growth. They were watered one hour before harvest, then cut at medium level. Fresh and dry weights were recorded and compared to the control.

Transplant Trials- General Method.

Equipment:- 1. 6.5 x 6.5cm vacopots or 12cm pots.
2. Seedlings, sown at set density (as outlined in each following experiment) in Levington Universal Compost.
3. Medium.

Pots were loose filled with medium, banged on the bench twice and levelled with a straight edge. Plants were transplanted, n/pot (dependent on species), 3 pots/treatment, and arranged in a randomised block design (3 blocks) under mist (20°C D, 13°C N). After 3 days they were removed from the mist and watered as required. Plants were harvested after 11 days growth by cutting at the level of the medium. To ensure full turgidity plants were watered one hour before harvest. Fresh and dry weights were recorded and compared to the control.

Conditions and procedures outlined in the general methods were adhered to throughout the developmental stage, except where otherwise stated.

Development of the General Methods.

1. Selection of Suitable Test Species and Sowing Densities for Seedling Trials

Species	Density	seed/g
Winter barley 'Panda'	1.5g/pot	24
	2.0g/pot	
Ryegrass	0.33g/pot	476
Lolium perenne	0.25g/pot	
Pepper 'Bell Boy'	0.5g/pot	128
	0.4g/pot	

Media

Control-Levington Universal Compost (peat and sand).
Cambark Fine (pine bark).
Spent Mushroom Compost,(1 year old).

Media were selected to give extremes of conditions. Bark is very low in nutrition and has a poor water holding capacity, whilst spent mushroom compost has an extremely high soluble salt content and high pH. Both these composts should give poor growth results. The control provides the 'ideal' medium comparison.

Reasons for Choosing Species

Barley - Sensitive to excess Ni and Al (36).
Indicator of low supply or availability of copper, phosphorus, nitrogen, and potassium. (25) Rapid germination and growth (47).

Ryegrass - Used by Anid et al (1983) Rapid germination and growth.

Pepper - Used by Frey (1981), who found differences in percentage germination on solid waste compost when compared to control.
Clear and distinct symptoms of iron, copper and zinc deficiency (25).

Results and Discussion (Full results Appendix 5)

Pepper took 14 days to germinate which was considered too long a period to be acceptable for a rapid seedling growth test.

Ryegrass plants were small very difficult to handle and time consuming to count (for germination percentage).

Barley proved the best test species with more rapid germination and growth of plants than the ryegrass. Weight per plant was similar for both sowing densities for both ryegrass and barley; the higher density was therefore chosen for future tests to give a larger total sample weight. No visible differences were observed between media treatments for any of the species.

2. Selection of Suitable Species and Planting Densities for Transplant Trials

In parallel with the seedling trials transplant trials were conducted. Species used for seedling trials were also considered for transplant trials and vice versa.

Species	Density
Winter barley 'Panda'	7 plants/12cm pot
	5 plants/12cm pot
Ryegrass	6 plants/vacopot
	9 plants/vacopot
Pepper 'Bell Boy' (18 days old)	14 plants/12cm pot
Antirrhinum 'Coronette Cherry'	48 plants/half seed tray

Media

Control- Levington Potting Compost (sphagnum peat).
Cambark Fine.
Spent Mushroom Compost,(1 year old).

Reasons for Choosing Species

Barley, Ryegrass and Pepper - as above.

Antirrhinum - Useful for indicating major element nutrition and high salinity (17).
Clear and distinct symptoms of N,P,K,Ca,Mg,S,B and Fe deficiency (102)

Results and Discussion (Full results Appendix 5)

Barley Fresh weight at harvest of plants grown in the control compost was much greater than that of plants in bark or spent mushroom compost. Bark gave the lowest figures for fresh weight where poor water retention and low nutrition suppressed growth. Plants in bark were pale and stunted with yellowing of the leaf tips. Those in spent mushroom compost showed signs of wilting and necrosis of the leaf tips after only 7 days. Fresh weight at harvest was only slightly higher than for bark. High soluble salt content in the spent mushroom compost caused slow establishment and limited water uptake. Barley is easy to transplant and shows good visible signs of high media salinity (leaf tip necrosis) and poor nutrition (leaf yellowing). When media were compared for weight of plants per pot, bigger differences were found with 5 plants per pot than with 7 per pot. Therefore it was concluded that 5 plants per pot should be used in future tests.

Ryegrass - Good differences were found between fresh weight of plants in the control compost and the other two media. However, ryegrass plants were rather small and difficult to handle for transplanting. Fresh weights were very small and required accurate measuring. For these reasons ryegrass was rejected as a future test plant.

Pepper - Good differences were found in fresh weights at harvest, with the control compost producing the heaviest plants and bark the lightest. Plants in spent mushroom compost were found to be wilting one day after transplanting, but later recovered turgidity. No visible differences were seen

at harvest between treatments. Pepper was kept in mind as a possible future test plant.

Antirrhinum - Again the control gave the greatest fresh weight at harvest, and bark the least. Slight colour differences were observed, plants in bark being the palest and those in the control the darkest. Antirrhinum was considered a good test plant, although 18 day old plants were somewhat small to transplant.

3. Comparison of Cereal Species as Indicators of Media Suitability for Plant Growth

Following on from the previous experiments in which barley was found to be a good test species it was decided to compare barley with other cereal species.

Species	Code	Density per 12cm pot
Winter wheat 'Maris Huntsman'	ww	5
Spring wheat 'Broom'	sw	5
Winter oats 'Pennal'	wo	5
Barley 'Panda'	b	5
Sweetcorn 'Jubilee'	s	5

Media

Control - Levington Potting Compost, (CON).
Cambark Fine, (B).
Spent Mushroom Compost,(1 year old), (M).

Reasons for Choosing Species

All are good indicators of major and minor nutrient status in the medium. All are fast growing and well documented (36,25).

Results and Discussion (Full results Appendix 5)

Wet and dry weights were recorded and analyses of variance performed. The summarised results of the two ANOVA can be seen in figure 5.1. Treatments joined by a line are not significantly different from each other (P=0.05 or less, see Appendix 5).

Dry Weight ANOVA

increasing weight

CONb Mb Bb CONww CONs Mww Bs Bww CONsw Ms Bsw CONwo Msw Bwo Mwo

Fresh Weight ANOVA

CONb CONs Bb Mb Bs CONww Mww Ms Bww CONsw CONwo Bsw Msw Bwo Mwo

COMPARISON OF CEREALS AS INDICATORS OF MEDIUM SUITABILITY FOR PLANT GROWTH. Fig. 5.1

Dry Weight

Winter Wheat

Dry weight of winter wheat grown in the control was significantly greater than that in bark, but not significantly different from spent mushroom compost. Visual differences were not great.

Spring Wheat

Control and bark grown spring wheat had significantly greater dry weights than M grown, but were not significantly different from each other. Yellowing of leaves of plants grown in bark and necrosis of tips of leaves in M was evident. Plants were, however, small and difficult to transplant. It was concluded that this species would perform better as a seedling trial plant than as a transplant trial plant.

Winter Oats

Oats grown in the control had a significantly greater dry weight than those in M, but were not significantly different from those in B. M and B were not significantly different. Oat plants had the lowest dry weights of all the species and were even more difficult to handle than spring wheat. Visual differences were not great, although indications of necrosis of leaf tips were seen after 4 days in M.

Barley

Dry weight of barley was significantly greater than for the other species, but no significant difference was found between media treatments for this species. Visual differences were not great.

Sweetcorn

The large size of these plants made them easy to handle. Differences in dry weight between treatments followed a similar pattern to those of spring wheat. Sweetcorn also exhibited the same type of visual differences as spring wheat, with signs of necrosis of tips of leaves showing after 4 days in M.

Fresh Weight (See fig. 5.1)

A slight difference can be seen between fresh and dry weight results. All species except sweetcorn gave fresh weights which were significantly greater for the control than for B or M. The percentage of water in plants grown on the control was obviously greater than for those grown on bark or spent mushroom compost. Differences were generally more significant when fresh weight was considered than for dry weight (see Appendix 5).

General Conclusion

Spring wheat and sweet corn were selected for further use as test plants, the former to be used as a seedling test plant. Both fresh and dry weights would be recorded in future; these taken together giving a measure of the lushness of growth i.e.:

$$\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times \frac{100}{1} = \% \text{ moisture content of the plant.}$$

4. Assessment of Species used by Previous Authors on a Wide Range of Media

Seedling Trial Species

	Density/6.5x6.5cm vacopot
Mustard (*Brassica nigra*)	0.5g
Cress (*Lepidium sativum*)	0.5g
Spring wheat 'Minaret' (mean 48 seeds/g)	2.0g

Transplant Trial Species

	Density	Age (days)
Antirrhinum 'Coronette Cherry'	5/vacopot	20
Stock 'Selectable Excelsior Mammoth Column Crimson'	4/vacopot	20
Sweetcorn 'Jubilee'	4/12cm pot	16

Media

	Code
Worm-worked Pig Slurry (1985)	P(85)
Worm-worked Cow Slurry (1985)	C(85)
Leafmould (Kew)	Lf
Cambark Fine	B
Spent Mushroom Compost	M
Sphagnum Peat	SP
Reading Pig Slurry Compost	RP
Doncaster Sewage/Refuse Compost	D
Levington Universal Compost	LvU
Levington Potting Compost	LvP

Reasons for Choosing Species

Mustard - Found to be a successful test plant for assessing growth media by Hadavizadeh (1982).

Cress - Found to be a successful test plant for assessing growth media (Hadavizadeh (1982)). Used in standardized tests for compost maturity (Spohn (1969) and Zucconi et al (1981)).

Spring wheat - Selected from previous tests above.

Antirrhinum - Selected from previous tests. Used successfully by Atkins (1968) and Waller and Wilson (1983).

Stock - Used by Atkins (1968) and Waller and Wilson (1983). Useful indicator of major element nutrition and copper toxicity.

Sweetcorn - Selected from previous tests. Used by Frey (1981) and Bernstein (1964).

Results and Discussion (Full Results Appendix 5)

Seedling Trial

Cress

Fresh Weight

increasing weight

<----------

LvP LvU C(85) D P(85) Lf RP M B SP

Dry Weight

increasing weight

<----------

LvP C(85) P(85) D LvU RP Lf M B SP

As expected spent mushroom compost (high salinity), bark (low moisture retention and low nutritional status) and sphagnum peat (low nutritional status) gave the lowest fresh and dry weights. Some differences can be seen in the order of the media with respect to plant weight between fresh and dry determinations. No visible differences were observed other than size.

Mustard

Fresh Weight

increasing weight

<----------

LvU LvP D C(85) Lf P(85) RP M B SP

Dry Weight

increasing weight

<----------

LvU C(85) LvP D P(85) Lf RP M B SP

Similar results to cress. No visible differences other than in size were found.

Spring Wheat

Fresh Weight

increasing weight

<----------

LvP	Lf	LvU	D	C(85)	RP	B	P(85)	SP	M
------		------				-------		------	

Dry Weight

increasing weight

<----------

LvP	Lf	D	LvU	C(85)	B	RP	P(85)	SP	M
			--------			--------			
		------			-----				

Slightly different results to cress and mustard were found with spring wheat, possibly reflecting a lower salt tolerance in spring wheat. High salinity media e.g. M, P(85), RP, gave poorer results relative to other media with spring wheat than with cress or mustard. No visible differences other than in size were observed.

Transplant Trial

Antirrhinum

Fresh Weight

increasing weight

<----------

LvU LvP Lf D M C(85) RP P(85) B SP

Dry Weight

increasing weight

<----------

LvU LvP Lf D M P(85) RP C(85) B SP

Antirrhinum gave a similar order of plant weight with medium type to the other species; the Levington composts giving the greatest weight, and sphagnum peat and bark the lowest. Visible differences were good as follows (from Oertli (1970)):-

LvU, LvP, D, Lf - Green and healthy showing balanced nutrition.

B, SP - Pale green leaves showing poor nutrition.

M - Yellow chlorotic upper and lower leaves, probably the result of high salinity causing mass nutritional deficiencies and specific

toxicities (see photograph 5.1).

C(85), RP - Some marginal chlorosis and necrosis on lower leaves showing unbalanced nutrition.

P(85) - Interveinal chlorosis on upper leaves showing iron deficiency possibly caused by unbalanced nutrition (see photograph 5.2).

Antirrhinum appears to be a good test plant for transplant trials.

Stock

Fresh Weight

increasing weight
<----------

C(85) LvU D LvP Lf RP M B SP P(85)

Dry Weight

Differences were not significant.

Differences between treatments were not as significant for stock as for the other species. Visual differences were not great. Plants grown in worm-worked pig compost were small and bluish, whilst other treatments produced lime green plants.
The poor performance and strange colouring of plants grown in P(85) (photograph 5.3) may be the result of a specific toxicity, probably copper (see table 2.8 and Atkins (1968)).

Sweetcorn

Fresh Weight

increasing weight

<----------

LvU Lf LvP RP SP D C(85) B P(85) M

Dry Weight

increasing weight

<----------

LvU Lf LvP RP SP D C(85) B P(85) M

Again, the order of weight with respect to medium type was similar to that found for the other test species. Sweetcorn and spring wheat growth was depressed more by the highly saline media (M, P) than that of the other test species, for which low nutrition in B and SP proved more detrimental on growth. Sweetcorn plants showed good visible differences between treatments as follows (25):-

LvU, LvP, Lf - Green and healthy all leaves, (balanced nutrition).

B, SP - All leaves slightly yellow, (low nutrition).

P(85), D - Slight necrosis of tips of lower leaves, (high salinity, possible specific toxicity).

RP, C(85) - Slight necrosis of tips of lower leaves and interveinal chlorosis,

(high salinity and unbalanced nutrition causing iron deficiency)(see photograph 5.4).

M - Extensive necrosis on all leaves, (very high salinity).

Sweetcorn appears to be a good test plant for transplant tests.

Photo.5.1 Antirrhinum. High Salinity Causing Nutrient Deficiencies and Possible Specific Nutrient Toxicities.

Photo.5.2 Antirrhinum. Unbalanced Nutrition Causing Iron Deficiency.

Photo.5.3 Stock. Probable Copper Toxicity Symptoms in Worm-Worked Pig Slurry.

Photo.5.4 Sweetcorn. Iron Deficiency Symptoms.

5. Determination of the Minimum Time Required to Show Differences Between the Media Treatments

To standardize conditions and minimize variation a Conviron model S10/S10H controlled environment incubator was used set at:- 80% RH (transplant trial),95% RH (seedling trial), 16 hours light, 8 hours dark (max light intensity), and 20°C during the light period, 13°C dark period.

Plants were harvested at:-

1. 7 days
2. 14 days after transplanting or sowing.

Plants were observed each day for visible differences. Fresh and dry weights were recorded, and % germination measured for spring wheat.

Species	Seedling Trial	Transplant Trial
	Mustard	Antirrhinum
	Cress	Stock
	Spring wheat	Sweetcorn

Cultivars and planting densities as for experiment 4.

Media Both trials.

	Code
Control-Levington Universal Compost	LvU
Cambark Fine	B
Spent Mushroom Compost	M
Worm-worked Cow Slurry (1984)	C(84)

Results and Discussion (Full results Appendix 5)

Seedling Trial, after 7 days growth

Mustard

increasing weight
<----------

Fresh Weight	C(84)	LvU	B	M
Dry Weight	C(84)	LvU	B	M

Visual differences:-

C(84), LvU - Green and healthy.

B, M - Patchy germination.

The differences were slightly more significant for dry weight than for fresh weight.

Cress

Fresh Weight	LvU	C(84)	B	M
Dry Weight	LvU	C(84)	B	M

Visual differences:-

C(84), LvU - Green and healthy.

B - Patchy germination.

M - No germination.

Spring wheat

Fresh Weight	LvU	C(84)	M	B
	----------		------	

Dry Weight	LvU	C(84)	M	B
	----------		------	

Percentage Germination

88%	87%	8%	0%
C(84)	LvU	M	B
---------		------	

Visual differences:-

C(84), LvU - Green and healthy.
M - Very few germinated.
B - No germination.

The differences were slightly more significant for dry weight than for fresh weight.

Results after 7 days show only the ability of the medium to perform as a germination medium over a short period of time.

After 14 days growth

Mustard

Fresh Weight	LvU	C(84)	B	M

Dry Weight	LvU	C(84)	B	M

Visual differences:-

C(84), LvU - Green and healthy.

M, B - Uneven germination and patchy growth.

Differences were slightly more significant for dry weight than for fresh weight.

Cress

Fresh Weight	LvU	C(84)	B	M

Dry Weight	LvU	C(84))	B	M

Visual differences:-

C(84), LvU - Green and healthy.

B - Uneven germination and patchy growth.

M - Uneven germination and patchy growth. Yellow leaves.

Again differences were slightly more significant for dry weight than for fresh weight.

Spring wheat

Fresh Weight	C(84)	LvU	B	M
	--------		------	

Dry Weight	C(84)	LvU	B	M
	---		---	

Percentage Germination

97%	96%	87%	65%
LvU	B	C(84)	M
---			---

Visual differences:-

C(84), LvU, B - Green and healthy.

M - Uneven germination.

Results after 14 days give a truer representation of the ability of a medium to support plant growth than those at 7 days. Poor moisture holding capacity in bark resulted in slow germination of all species thus causing a low weight of plants after 7 days. By 14 days most seeds had germinated and plants were growing reasonably well, whilst in spent mushroom compost poor germination and growth were still evident. Daily observations showed that all seed types emerged after 3 days in Levington Universal compost, 4 days in C(84) and a few seeds of mustard and cress had germinated after 4 days in bark. By 5 days a few mustard plants had emerged in M and a few spring wheat in B. It took 7 days for spring wheat and 10 days for cress to germinate in M. A trial period of 14 days should allow sufficient germination and growth of these test species for meaningful comparison of media. Daily observation is necessary to supply additional information to the simple weight determinations on media performance.

Transplant Trial-after 7 days growth

Antirrhinum

Fresh Weight	LvU	C(84)	B	M

Dry Weight	LvU	B	C(84)	M

Visual differences:-

LvU, B	- Green and healthy.
M	- Yellow upper leaves.
C(84)	- Interveinal and marginal chlorosis on upper leaves.

The level of significance was similar for fresh and dry weights.

Stock

Fresh Weight	LvU	C(84)	B	M

Dry Weight Differences not significant.

Visual differences:-

LvU, C(84), B	- Lime green leaves.
M	- Bluish colouring and wilting of leaves.

Sweetcorn

Fresh Weight
Dry Weight
} Differences not significant.

Visual differences:-

LvU, C(84), B - Slight wilting and some necrosis of leaf tips.

M - Severe necrosis of leaf tips on all leaves.

Sweetcorn grew very badly in the incubator with most plants actually losing weight when compared to plants weighed at the time of transplanting. Low light levels and high humidity were thought to be the cause. Humidity was reduced to 65% after the first week, but light intensity could not be increased. This species grew better in the greenhouse.

After 14 days growth

Antirrhinum

Fresh Weight	LvU	C(84)	B	M

Dry Weight	LvU	C(84)	B	M

Visual differences:-

LvU - Green and healthy.

B - Slightly pale green.

M - Yellow upper leaves with some necrosis.

C(84) - Interveinal chlorosis on some plants.

The differences were slightly more significant for dry weight than for fresh weight.

Stock

Fresh Weight	LvU	C(84)	B	M

Dry Weight	LvU	C(84)	B	M

Visual differences:-

LvU - Green and healthy.

B - Slightly yellow.

M - Upper leaves bluish, older leaves yellow over veins.

C(84) - Some interveinal chlorosis on upper leaves. Some sunken necrotic lesions on tips of new leaves.

Sweetcorn

Fresh Weight	LvU	B	C(84)	M

Dry Weight	LvU	B	C(84)	M

Visual differences:-

C(84), LvU - Green leaves, some tip necrosis on older leaves.

B - Pale green, some tip necrosis on older leaves.

M - Severe necrosis on tips of all leaves.

More than 7 days were required to show significant

differences between media for weight of stock and sweetcorn. Differences increased in significance for antirrhinum after 14 days from those found at 7 days. Some visible differences were observed in all species after 7 days, but these were more pronounced after 14 days.

General Conclusion

Daily observations of plants over 14 days followed by weight determination (fresh or dry weight) should give a good indication of the ability of a medium to support plant growth. A general discussion of these seedling and transplant test techniques can be found in the general discussion section of this thesis.

Evaluation of Analytical Techniques

Mustard, cress, spring wheat, sweetcorn, Antirrhinum and stock fresh weights were correlated to medium pH, conductivity (us/cm), volume percent air (air), water holding capacity (at container capacity) (whc) and bulk density (BD).

No significant correlations were present for Antirrhinum and stock. The following significant correlations were found. Figures for B and SP were omitted as being below the optimum level of conductivity for growth i.e. before the peak of the normal distribution of conductivity vs plant weight as illustrated in fig. 5.2 for conductivity vs sweetcorn (maize) fresh weight. All the correlations for conductivity were therefore negative.

Mustard	r^2%	df
us/cm	55.8***	22
us/cm+air	59.7***	21
us/cm+whc	54.0***	21
us/cm+pH	54.0***	21
us/cm+air+pH	58.1***	20

Cress	r^2%	df
us/cm	32.6**	22
us/cm+air	31.1**	21
us/cm+whc	32.3**	21
us/cm+pH	49.5***	21
us/cm+air+pH	49.0***	20

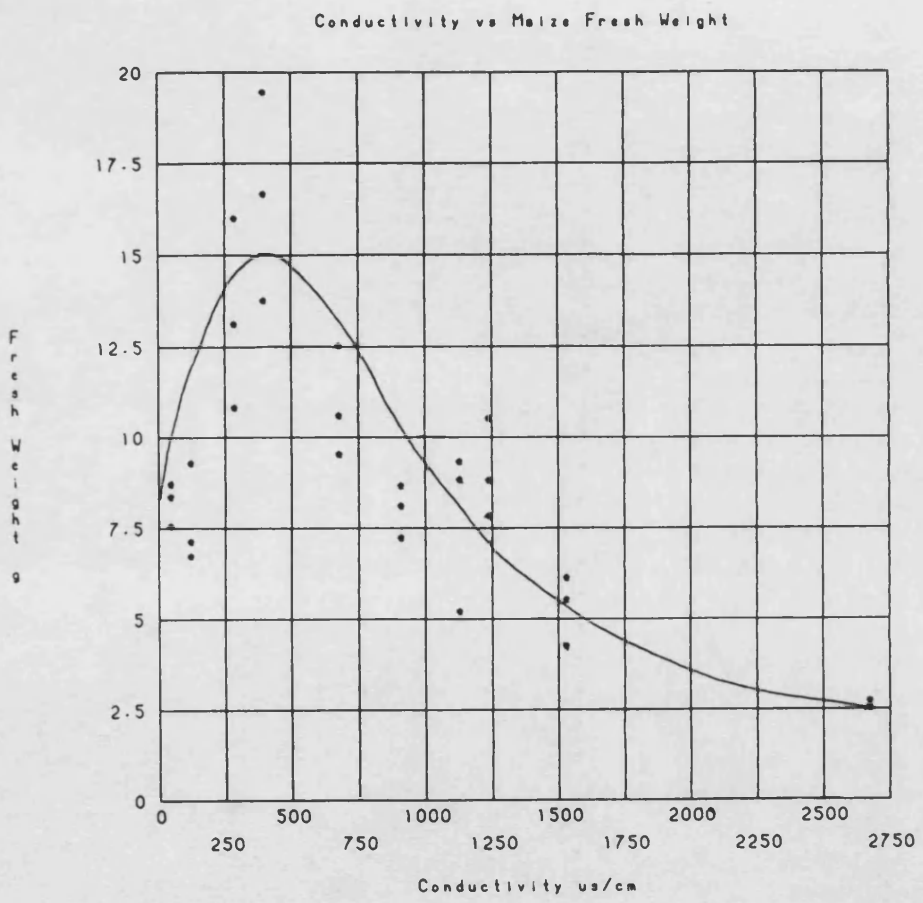
Spring Wheat	r^2%	df
us/cm	84.8***	22
us/cm+air	87.1***	21
us/cm+whc	84.4***	21
us/cm+pH	84.1***	21
us/cm+air+pH	86.6***	20

Sweetcorn	r^2%	df
us/cm	70.6***	22
us/cm+air	75.3***	21
us/cm+whc	69.8***	21
us/cm+BD	69.2***	21

Conductivity was obviously the single most important factor of those tested in governing the growth of the seedling test plants and transplants of sweetcorn. Conductivity and volume percent air in combination appeared most influential over growth for mustard, spring wheat and sweetcorn, whilst us/cm+pH was marginally of greater significance than us/cm alone for cress. The relationship between volume percent air and growth was positive for all species. i.e the greater the volume percentage of air the better the growth. This is understandable since young plants in a relatively large amount of medium are probably at more risk of overwatering than older rapidly transpiring plants in a relatively small quantity of medium. Hence another possible reason for the absence of significant correlations between volume percent air and growth in the nursery stock species.

These results agree with those for chrysanthemum in that the growth of young plants is significantly negatively correlated with the conductivity of the medium extract. This is apparently species dependent, since Antirrhinum and stock growth did not

correlate significantly with conductivity in a linear form, and no evidence of more complex relationships (e.g. quadratic, normal distribution) was found.



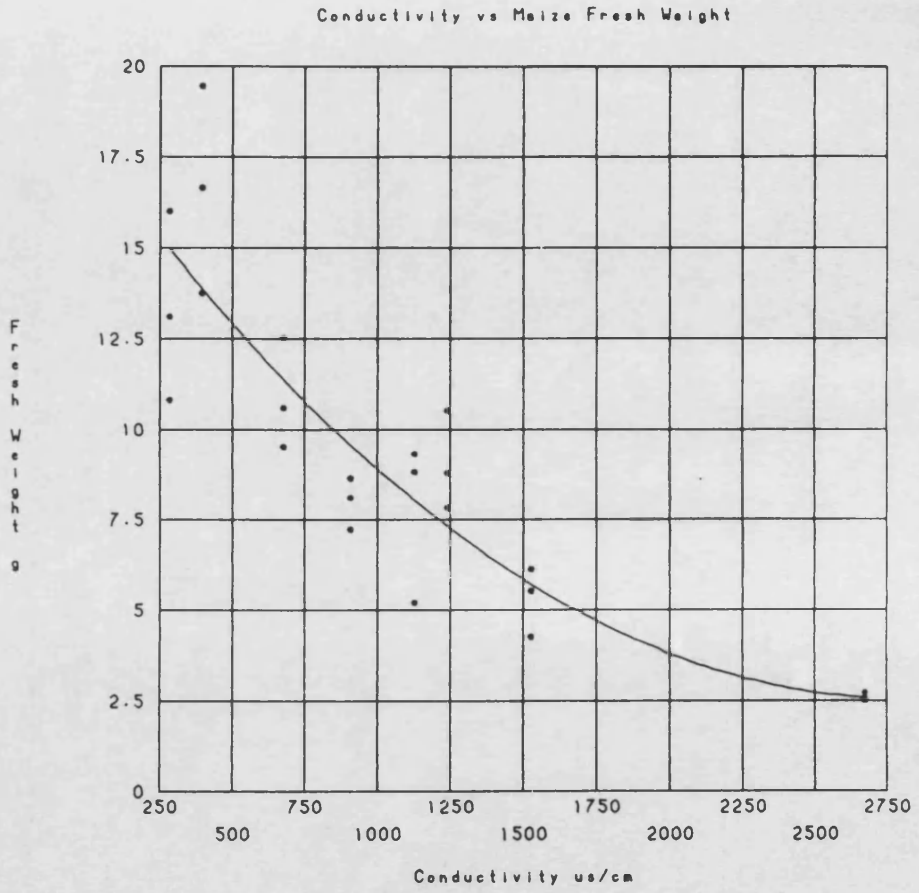


Fig. 5.2 Conductivity vs. Sweetcorn Fresh Weight.

1. Including B and SP figures.

2. Excluding B and SP figures.

CHAPTER 6

Overall Discussion and Conclusions

Medium Shrinkage, Physical Properties and Nursery Stock Growth

Bark The addition of peat or peat + sand to bark improved the waterholding capacity greatly (see table 3.11), but had little effect on the shrinkage pattern. An improvement in the water retention, and perhaps the cation exchange capacity, account for the improved growth of the nursery stock plants grown in B2 and B3 over those in B1, since all three treatments contained equal quantities of fertilizer.

Doncaster Compost The amendments of peat and perlite decreased the water holding capacity slightly whilst not having a large influence over shrinkage. This did not apparently affect growth detrimentally as plants in D2 grew better in several cases than those in D1 or D3. The lower conductivity of D2 than the other two treatments may account for this observation.

Worm-Worked Pig Slurry The amendments reduced the shrinkage and the water holding capacity and volume percentage air of the media to similar levels to the control. The lower conductivity and pH of P2 may account for the better growth in this medium than in P3 in most cases.

Worm-Worked Cow Slurry The addition of peat and coarse sand increased the volume percent air and decreased the water holding capacity. The greater the proportion of peat, the lower the water holding capacity, conductivity and pH and the less the effect on limiting shrinkage in the mixtures.

Spent Mushroom Compost Whilst perlite and coarse sand had similar effects on shrinkage, the addition of perlite as an amendment decreased water holding capacity and increased aeration. Coarse sand on the other hand had little effect on water holding capacity but decreased aeration. Fitting together of particles must have occurred in the latter case, whilst the reverse procedure occurred in the perlite mixture.

Hypericum and Spiraea apparently benefitted from this improved aeration (M3 plants grew slightly better than those in M2) whilst Santolina and Senecio grew equally well in both mixtures and Rubus plants grew slightly better in M2, possibly benefitting from the higher water holding capacity.

Leafmould The addition of sphagnum peat decreased the water holding capacity and increased the aeration of the leafmould treatments. Both Lf2 and Lf3 were roughly similar for shrinkage, physical properties and growth response. The benefit from the addition of peat was probably derived mainly from the increased aeration achieved. An amendment more resistant to physical breakdown would be required to reduce shrinkage.

Recommendations for Medium Mixes

Several of the media performed perfectly well without physical amendment (i.e. with only chemical amendment) for tomato in particular, and to a lesser extent for chrysanthemum because of lower salinity tolerance in the latter. The yield of tomatoes was equal or better than that for the control (SPCF2) for spent mushroom compost, Levington Potting compost, worm-worked cow and worm-worked pig slurries, all

four requiring little additional fertilizer to improve yields over the control. The quality of the tomatoes grown in P was, however, reduced for commercial purposes, the nutrient levels possibly being excessive. Dilution or leaching of P would be advisable even for tomato crops. For chrysanthemum and other species with similar salt tolerance, the addition of base dressing and liquid feed to leafmould and bark at the recommended rate for sphagnum peat is sufficient to give equal size and quality of plant to that grown in peat. However, as can be seen from the second chrysanthemum trial, size and quality can be improved by the addition of 50% peat (by vol) to bark, and for leafmould 1 part sphagnum peat:3 parts leafmould is recommended.

The performance of the higher conductivity media (C, P, M) was improved greatly by dilution with peat, bark or vermiculite. It is recommended that < 30% M (of the conductivity found here) and 25-50% C, P and RP should be used for chrysanthemum media. Municipal refuse compost performed badly in both chrysanthemum trials, possibly because of high pH and toxic levels of boron (in Lescost) and other heavy metals. Cadmium levels in tomato fruit grown in Lescost were elevated over the control, suggesting that it would be inadvisable to use this type of medium for food crops, and that care should be taken in handling it.

The nursery stock media are discussed above with reference to shrinkage. Addition of peat to bark media is recommended to improve water holding capacity, ratios of 3:7 bark:peat and 1:2:1 bark:peat:coarse sand being used here. The addition of 25-50% peat to leafmould is also recommended. 25-50% worm-worked slurry in a mixture with peat and coarse sand improves growth over 100% worm-worked slurry, and 25% spent mushroom compost is suggested

as a maximum for nursery stock. Amendment of the Doncaster municipal refuse/sewage sludge compost had little influence over growth, even as little as 30% D (as in D2) being apparently depressive on growth. (N.B. all percentages are by volume).

Seedling and Transplant Trials

Ranking of the media in order of growth response (i.e. weight) for trial 4 shows similarities between the species (both seedlings and transplants). M, P(85), SP, B and RP generally appear towards the lower end of the scale, and LvU, LvP, Lf, C(85) and D the upper end. A similar ranking can be seen for treatment 1 of the nurserystock trial (although these media had additional slow release fertilizer and are not strictly comparable). It appears therefore that seedling or transplant trials can reflect later growth. Frey (1981), however, found that different species behaved differently with respect to germination of pea, corn, marigold, cucumber, tomato and pepper in municipal refuse compost. The difference in response was attributed to differences in salt tolerances between the species. The species used here may be similar in their salinity tolerance, thus giving similar results. The use of species with high or low salinity tolerance, relative to the majority of plants, may be indicated. The species used here belonged to only three different botanical families (Cruciferae, Gramineae & Scrophulariaceae.) The inclusion of representatives from other families would widen the range of information derived from these tests, possibly giving an indication of the growth responses of related species.

What are the benefits of using small scale growth trials over chemical or physical analyses?. Davis

(1979) states that although standard plant tests take longer to complete than soil analysis, they are easy to set up and give more direct results. The results here suggest that they are useful in showing effects of different nutrient balances on growth of particular species, and if growth of seedlings and transplants can be shown to predict growth of larger plants, short term tests could be useful in research for collecting information on species differences. Interpretation of seedling and transplant tests is, however, complicated. Basically only four types of information can be derived:

1. The medium is nutrient deficient causing slight chlorosis and stunting.
2. The medium is excessively saline giving chlorosis, necrosis, blue colouration of leaves, wilting or stunting.
3. Unbalanced nutrient status in the medium causing interveinal or marginal chlorosis. Leaf analysis may give an indication of medium nutrient status.
4. Specific species response.

Most of this information (except 4.) can also be derived from media analyses. Short-term growth trials are unlikely to be used for advisory work because they are time consuming and there are difficulties in interpretation, but for research purposes they may be useful in providing a pool of information, on the basis of which, recommendations can be made.

Medium Characterization and Analytical Techniques

Physical Properties

The equation of Hanan et al (1981) relating total porosity to bulk density was used to convert the volume percent air based on saturated porosity to a total porosity basis for the media in this study (see table 2.9). The results can be seen in table 6.1. The total porosity and volume percent air thus converted compare well with the figures quoted by Verdonck et al (1981) for sphagnum peat and also with the figures of Günther (1983) for bark and sphagnum peat, and with those of Lemaire & Dartigues (1985) for spent mushroom compost. Porosity at saturation was significantly correlated to total porosity as calculated from the bulk density ($P=0.05$, $r=0.58$ at 11 degrees of freedom) by the following equation:-

Water content at saturation (% of total vol.) = 8.7 + 0.804 Total Porosity (Hanan et al)

This relationship, although significant, is not particularly good. The estimation of total porosity using the saturated water content and the method employed here is obviously not accurate for all media. It is possible, particularly with the more porous media, that some water was lost while transferring from the bucket to the balance. Also air may have been trapped inside the medium, preventing full saturation. The use of the bulk density to estimate total porosity seems preferable to attempting to measure it directly.

The relationships given in chapter 2 for converting bulk density and volume measurements from one method to another ought to be useful; however, since

virtually no significant correlations were found at all between growth and physical properties of the medium, the usefulness of measuring these properties at all may be in doubt. Physical amendments, based on the analytical methods used here did, in most cases, improve the growth of the chrysanthemums in trial 2, and of the nursery stock, over unamended treatments. This improvement however, can be partly explained by the dilution of saline media with media low in soluble salts and is, therefore, partially due to the alteration in chemical properties. It appears that plants can tolerate a wide range of physical properties, and irrigation rates can easily be altered to suit the medium. Only in extreme cases when excessive irrigation (because of a low water holding capacity) leads to loss of nutrients or water logging causes insufficient aeration, are physical properties likely to be of great importance. Also, from a practical view point, bulk density will be important for handling purposes and will be used as the basis for chemical analyses. For initial characterization of a type of medium the water release curve technique in addition to a method for determining water and air content at container capacity may be used and for routine advisory purposes, bulk density and the proportion of particles < 0.5mm in diameter, in addition to chemical analyses, should give sufficient information for recommending physical amendments. A calibration connecting particle size distribution to phase distribution would be necessary but this requires further experimentation.

MEDIUM	VOL. % TOTAL POROSITY (HANAN ET AL)	VOL. % AIR AT CONTAINER CAPACITY BASED ON TOTAL POROSITY (HANAN ET AL)
Levington Universal	86.4	10.8
Levington Potting	92.7	17.1
Sphagnum Peat	93.8	20.2
Sedge Peat	91.4	7.3
Cambark Fine	91.5	50.9
Kew Leafmould	83.7	5.1
Beech Leafmould	93.9	32.2
W.W Cow Slurry	93.1	4.5
W.W Pig Slurry	89.5	13.6
Pig Slurry Compost	92.2	16.1
Spent Mushroom	87.6	17.6
Lescost	84.9	19.4
Doncaster Compost	80.5	18.2

Total Porosity and Vol. % Air Space Calculated from Hanan et al Equation. Table 6.1

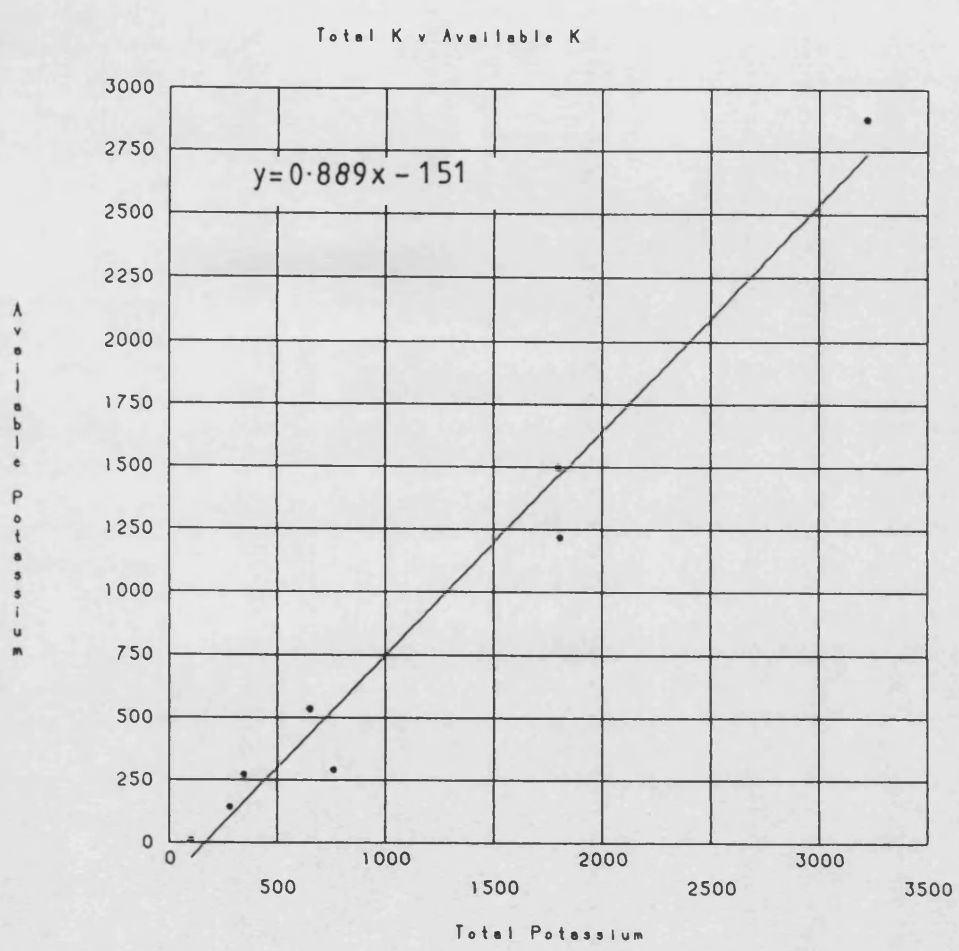
Chemical Properties

Success of Analytical Techniques

Total and available nutrient analyses (1984 results) were found to be significantly correlated (P=0.001) for phosphorus, potassium, zinc, copper, calcium, sodium, nickel and cadmium, as illustrated by the examples in fig. 6.1. Magnesium (P=0.01) and iron (P=0.05) total and available levels were also significantly correlated. The equations found can be seen in Appendix 6.

The total nutrient levels give an indication of the reserves of nutrients that may become available with time, through breakdown of particles. This measure is of interest in initial characterization of the medium, and particularly with long-term crops in mind (e.g. those growing over a matter of months), the reserves possibly acting like a slow release fertilizer. For short-term crops (e.g. those growing over a few weeks rather than months) the measurement of CEC may be of more relevance, giving a measure of the ability of the medium to hold and release nutrients, during a period when little physical breakdown of the medium is expected.

The fact that available nutrients, as measured by the 1:6 v/v moist medium:water extract, are (in several cases) highly correlated to total nutrients (dry ashing method), makes it possible to use the simpler available nutrient method to predict reserves. It also shows that the analytical methods used are suitable for a wide range of organic waste media.



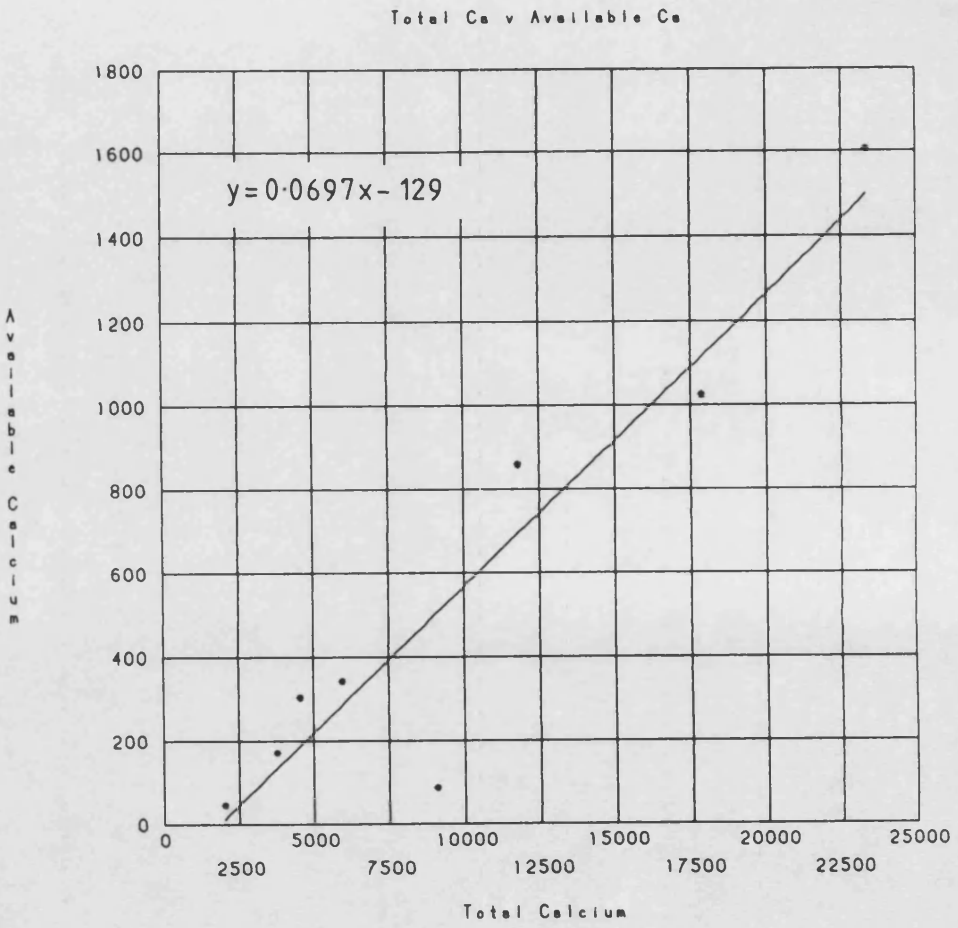


Fig. 6.1 Relationships Between Total and Available Nutrient Levels.

Simple and Multiple Correlation Techniques

The use of multiple correlation techniques helps to outline which factors (in combination) are most influential over growth or yield e.g. for tomato available N + K + Ca were more highly correlated to yield than other combinations of nutrients. In this case it is suggested, that only these three nutrients need be measured to assess yield (using the equation Yield (g) = 346 + 1.36K + 1.48N + 1.18Ca, nutrients in mg/l). Since available K and Ca are highly correlated to each other and are likely to cancel each other out in multiple correlations (the inclusion of both together giving little improvement in the value of r^2 over either used alone, in combination with uncorrelated nutrients) it can be argued that only N + Ca or N + K need be measured to assess yield; the latter two nutrients being most likely to influence yield. The following equation was found for available N + K vs. yield:

$$\text{Yield} = 336 + 6.28K + 0.549N$$

For chrysanthemum the inability to find significant correlations between medium nutrient levels and growth (as measured by dry weight) was described and discussed in chapter 3. However, significant correlations were found for medium vs. leaf nutrients (simple correlations) suggesting that medium nurient status can be assessed by plant uptake for chrysanthemum.

The correlation between medium and leaf nutrient analysis for chrysanthemum and correlations between medium nutrient levels and yield for tomato show that medium nutrient levels as measured by the methods used here give a meaningful prediction of the response of the plant. The medium conductivity, pH and nutrient levels are shown to be the most

important factors governing plant growth. The significant correlations between seedling growth and conductivity, and dry weight of chrysanthemum pinchings and conductivity, illustrating the particular influence of salinity over growth of young plants. Whilst this fact is hardly new, it is used here to emphesize that physical properties appear less important than is suggested by many authors, since these are monitored, albeit subconsciously, by the grower.

Conclusions

The analytical techniques used in this study for chemical properties (particularly the conductivity level) can be used to predict plant response (e.g. growth or yield). The determination of physical properties is largely unnecessary for advisory purposes (excepting bulk density) once the medium type has been characterized. It seems unlikely that the grower will attempt to use any medium that has not been thoroughly researched and tested, owing to the high value of horticultural crops, so any medium sample should be recognizable to an advisory analyst, and specific background information would be available.

If all researchers and advisory workers used the same techniques for analysis (or had correlations to convert one method to another) information could be pooled to give a large amount of data which could perhaps be computerized and on which recommendations could be based. The SME and 1:1.5 water extract have come to the fore as favourites as standard methods. Both require some expertise or equipment; to achieve saturation of the medium for the SME technique or standardization to pF1.5 for the 1:1.5 edxtract.

Johnson (1980) showed that the 1:1.5 extract correlated significantly to the Levington 1:6 water extract as used here. The suggestion here is that the 1:6 extract (which does not require standardization of the medium to a particular moisture content) should be used for advisory purposes, and the 1:1.5 extract or SME for research purposes. It would be necessary to determine whether the correlation found by Johnson (1980) remains true for a wide variety of media.

Short-term growth trials are likely to be of use in research, but not for advisory purposes. They are difficult to interpret without further analysis, and do not provide information that can be used by the grower in making his own amendments (unlike nutrient content data).

It is suggested that for advisory purposes an initial conductivity and pH reading can indicate whether a full fertilizer addition can be made (media with conductivity <200 us/cm) or whether further nutrient analysis is required to determine the nutrient balance. Media with excessive initial conductivity can be diluted with a low conductivity amendment, or leached before further analysis. Physical amendment can also be made at this stage according to bulk density, and perhaps a measure of the content of particles <0.5mm (if this method proves to be reliable in estimating the phase distribution) or a direct measure of water relations using a method such as that employed here. The latter is much too time consuming for advisory purposes, but could be of use in collecting initial data on new types of media, and this data could be used in making recommendations. The purpose for which the medium is to be used, or whether it comes from an established crop, should be known before analysis, so that

specific recommendations and adjustments can be made.

Suggestions for Further Work

Physical Analyses

Experiments could be performed to assess:

1. The influence of physical properties on growth (whilst keeping the chemical properties constant), with the aim of determining the significance of correlations between the two. It may be preferable to use only one type of medium at a time. This could be used to develop or test a standardized method of physical analysis.

2. The influence of particle size distribution on phase distribution. Standard methods of physical analysis should be adopted wherever possible. This may require liason with other workers researching similar subjects.

Chemical Analyses

Further work is required to determine whether the regression equations found by Johnson (1980) relating nutrient anaysis results for the 1:6 and 1:1.5 extracts remain true for a wide variety of organic media.

Shrinkage

The development of a quick method for assessing likely shrinkage of media with time e.g. a method of acid degradation such as that used for the determination of fibre in forage, may be useful. The length of time the medium is exposed to the acid, or the strength of the acid, could be gradually increased, so that a curve of organic matter degradation with time (or acid strength) could be plotted and compared to actual shrinkage in the pot over time.

Seedling/Transplant Trials

Further investigation of the usefulness of these techniques may be indicated, to determine whether short-term trials can predict later growth. Comparison of short- and longer-term trials using the same species is suggested.

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APPENDIX 1

BSI

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British Standards Institution

Technical Committee FAC/2 -
Top soil and other growing media

Our tel ext/ref FAC/2

Date 24 Septemebr 1984

PROPOSAL FOR METHOD OF MEASURING BULK DENSITY FROM
BRITISH PEAT PRODUCERS ASSOCIATION

JSP/ml

Head Office 2 Park Street London W1A 2BS Tel 01-629 9000 Tx 266933 BSILON G
Information Services and Marketing Linford Wood Milton Keynes MK14 6LE Tel 0908 320033 Enquiries Tel 0908 320066 Tx 825777
Quality Assurance Division Maylands Avenue Hemel Hempstead Herts HP2 4SQ Tel 0442 3111 Tx 82424 BSIHHC G
Manchester Office 3 York Street Manchester M2 2AT Tel 061-832 3731 Tx 665969 BSIMAN G

Form 2-6305

PEAT PRODUCERS ASSOCIATION (UK) LTD.

BULK DENSITY OF PEAT AND PEAT-BASED GROWING MEDIA - MODIFICATION OF THE DRAFT AFNOR NORMES METHOD, CODE NAMED 'FIBSPAN'

1.0 PRINCIPLE

1.1 Determination of bulk density by filling the prescreened growing medium, with the assistance of a further (fixed) screen and a funnel, into a test cylinder, application of static compaction and weighing the contents of the cylinder.

2.0 APPARATUS

2.1 A 1000 cc Testing Cylinder whose internal height does not exceed its internal diameter by more than 17%.

2.2 A removable collar 5 cm. high and of an identical internal diameter to the cylinder.

2.3 A plunger weighing 650 gms., having a diameter 5 mm smaller than the cylinder and collar.

2.4 A 60° funnel, upper diameter 17 cm., lower diameter to fit the collar.

2.5 A BS410/1946 perforated plate screen having ¾" (19.05 mm.) square apertures, fixed independantly approximately 5 mm. above the funnel, and not connected to the funnel or cylinders. (A tripod support has been found convenient).

2.6 A rectangular-ended scoop approximately 15 cms. long and 5 cm. wide.

2.7 Scale sub-divided 1 gm.

3.0 PROCEDURE

3.1 From the sample to be tested approximately 2 litres of peat/growing medium is spread out on the bench, any lumps broken up gently with the fingers, and the whole gently passed through a ½" (13 mm) screen. Undue force must not be used in this process, since with wetter peats the resulting change in structure has been found to affect the result. (See also 3.7 below.)

/cont

3.2 Using the scoop, by means of gently passing the sample through the ¼" fixed screen into the funnel, fill the testing cylinder surmounted by the removable collar just to the top edge of the latter.

3.3 Strike off the surface with a straight edge or with a wire grid having ca.1" apertures.

3.4 Carefully put the plunger in place, let stand for 3 minutes, then carefully remove it.

3.5 Carefully lift off the removable collar, then strike off the surface with a straight edge or wire grid.

3.6 Weigh the test cylinder and its contents to the nearest gram.

4.0 CALCULATION OF RESULT

4.1 If m is the mass in grams of the test cylinder and the material which it contains

If m_0 is the mass in grams of the empty test cylinder

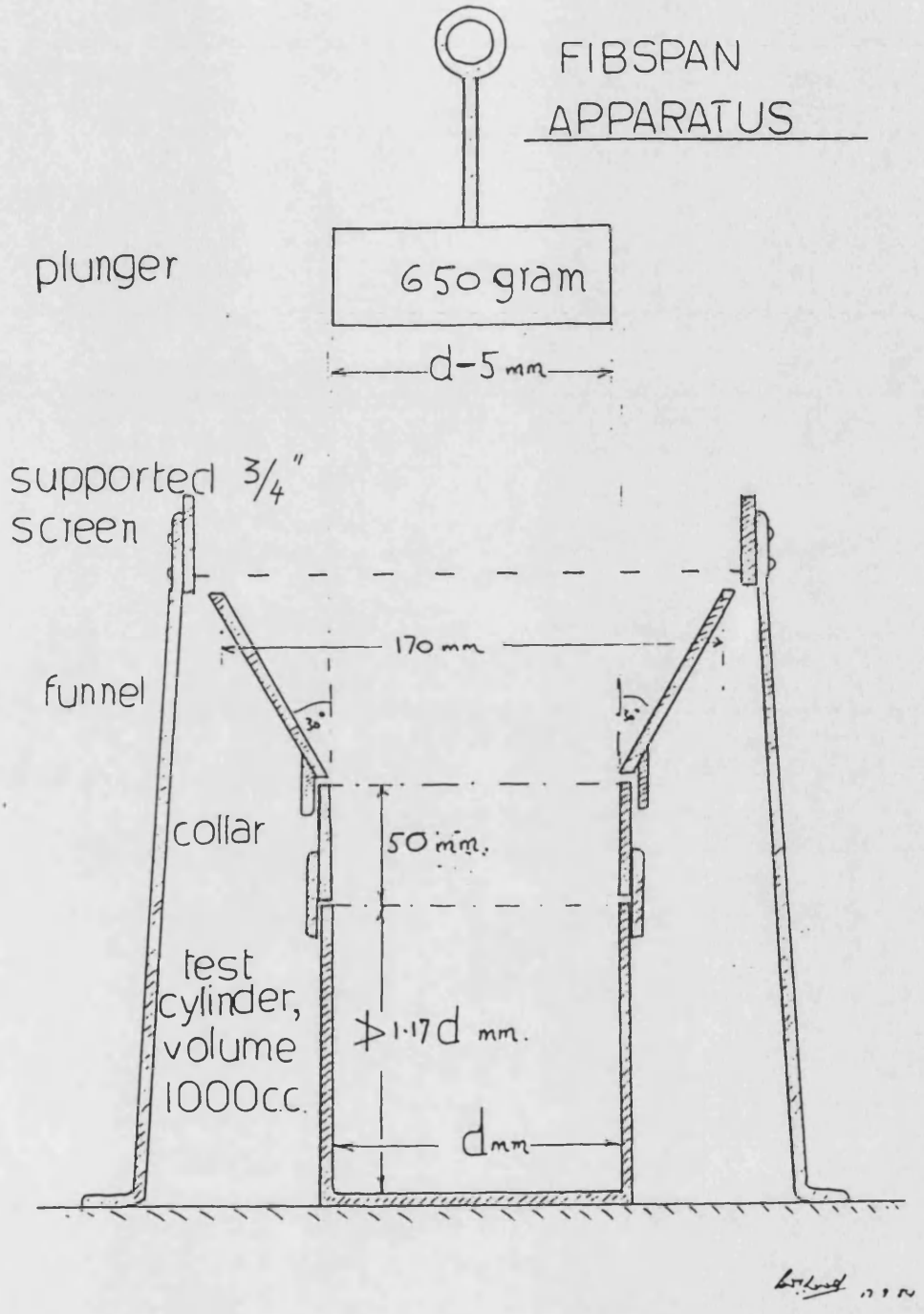
If V is the volume in litres of the test cylinder

4.2 The bulk density p is given by the formula

$$p = \frac{m - m_0}{V} \quad \text{g/litre}$$

Peat Producers Association (UK) Ltd./FAL/2

FIBSPAN APPARATUS



APPENDIX 2

Properties of Sphagnum Peat.

Bulk density:- 60-100g/l

pH :- 3.5-4.0

Nutrient	Total mg/l fresh compost
N	2500
P	10-50
K	40
Ca	200
Mg	150
Cu	0.11-1.32
Fe	17.5-112.0
Mn	0.16-0.46
Mo	0.017-0.06
Zn	0.6-1.0

From Bunt (1976).

Recommended Levels of Nutrients for addition to British or Irish Sphagnum Peat as a Base Dressing. (mg/l) (44)

Nutrient	Seed 50% peat 50% sand	100% Peat: Salt Sensitive Plants	Mod. Salt Tolerant	Salt Tolerant	Chrysanthemum Compost	Tomato Compost
N	-	88	140	210	225	175
P	60	120	120	120	150	240
K	152	210	315	420	200	630
Ca	1328	2115	2515	2515	1500	2770
Mg	-	390	390	390	225	360
B	-	4	4	4	1.3	4
Cu	-	17.2	17.2	17.2	20	17.2
Fe	-	55.2	55.2	55.2	150	55.2
Mn	-	21.6	21.6	21.6	1.5	21.6
Mo	-	4	4	4	-	4
Zn	-	17.2	17.2	17.2	40	17.2

FRITTED

Examples:-

Salt Sensitive	Moderately Salt Tolerant	Salt Tolerant
Primula obconica	Lettuce	Chrysanthemums
Azalea	Cucumber	Carnations
Celery	Other vegetables	Tomatoes

Desirable Indices for crops during the growing season*

	pH	P	K	Mg	NO_3N	Conductivity Not exceeding
TOMATOES) beginning IN) of crop PEAT)	5.8-6.5	7-8	5	4	4-5	5
MODULES) later in) modules	5.8-6.9	5	5	4	4-5	5
CARNATIONS	5.8-6.5	5-6	5	4	4	5
BEDDING PLANTS	5.8-6.5	5	3	4	4-3	3
SEED COMPOST	5.8-6.5	4	2	2	1	1
CUCUMBERS) beginning IN) of crop PEAT)	5.3-6.5	8	5	4	5	4
MODULES) later in) season	5.8-6.9	6	4	4	5	4
POT PLANTS	5.8-6.5	5	3	4	4-3	4
NURSERY STOCK - ERICACEOUS	5.0-5.5	4	3	4	2	2
- GENERAL	5.8-6.5	4	3	4	3	3

* New unused composts levels may be outside these limits.

INTERPRETATION OF AMMONIA N INDICES

Index 0, 1	Low, normal values for composts in use
2, 3	Normal values for unused composts
4	High, may affect young plants
5	Very high

NB: On a fresh unused compost NO_3N + NH_4N should not exceed :-

400 mg/l for a potting compost or growing bags
150 mg/l for a seedling compost

For growing bags more than 200 mg/l is undesirable, but damage is not likely below 400 mg/l N.

Revised Classification of Analytical Data for Loamless Composts (Levington Method)

Index	P mg/litre	K mg/litre	Mg mg/litre	NO_3-N mg/litre	Conductivity micro siemens	NH_4N mg/litr
0	0 - 4	0 - 25	0 - 5	0 - 15	0 - 150	0 - 20
1	5 - 7	26- 50	6 - 10	16- 25	151- 300	21-50
2	8 - 11	51- 100	11- 15	26- 50	301- 400	51-100
3	12- 18	101- 175	16- 25	51- 80	400- 500	101-150
4	19- 28	175- 250	26- 35	81-130	501- 600	151-200
5	29- 40	251- 400	36- 50	131-200	601- 700	> 200
6	41- 55	400- 650	51- 85	201-300	701-900	
7	56- 75	651-1000	86-150	> 300	901-1100	
8	76-100	1000-1500	151-200		1101-1300	
9	> 100	> 1500	> 200		> 1300	

APPENDIX 3

APPENDIX 4

Some Interactions between Nutrients in Potting Soils with respect to Plant Uptake.

Nutrients involved	Interaction
K:Mg ratio	K:Mg >3:1 likely Mg deficiency and vice versa.
N:P:K	High N, low P + low K :- soft vegetative growth and reduced reproduction.
	V. high N,P or K :- high conductivity giving hard stunted growth.
B	Deficiency below 0.5mg/l Toxicity above 3mg/l (in the compost).
$NH4^+$, Cu	High ammonium leads to a requirement for high copper levels.
Mn, Fe	Low manganese availability causes low iron availability and possible deficiencies.
$NO3^-$:$NH4^+$	High $NO3^-$:$NH4^+$ ratio decreases the availability of molybdenum.
$NO3^-$-N,P205, Fe	High P205 or $NO3^-$-N levels leads to a decrease in iron levels with likely deficiency.
K:Ca , Fe	High K:Ca ratio may result in Fe deficiency.
pH,P,B,Cu,Fe,Mn,Zn	High pH (>6.0) causes reduced availability of these elements. Deficiences of Cu occur when 4.5>pH>6.0

N.B. This table refers to available nutrient levels in general terms. What is 'high' or 'low' will depend on the individual plant,the species, and the conditions under which it is grown.

APPENDIX 5 Seedling and Transplant Trial Results

	Medium	Seed Quantity(g)	Fresh Weight(g)	Number Of Plannts	Percentage Germination	Weight per Plant(g)
Barley	Peat	1.50	6.928	32.0	89	0.217
		2.00	8.903	44.3	93	0.201
	Bark	1.50	3.674	31.7	88	0.116
		2.00	4.903	44.0	92	0.111
	Spent Mushroom	1.50	3.402	31.3	87	0.108
		2.00	3.450	37.7	79	0.092
Ryegrass	Peat	0.25	0.928	99.7	84	0.009
		0.33	1.290	143.0	90	0.009
	Bark	0.25	0.471	108.0	91	0.004
		0.33	0.729	145.3	92	0.005
	Spent Mushroom	0.25	0.235	73.0	61	0.003
		0.33	0.257	97.7	61	0.003

1. Selection of Suitable Test Species and Sowing Densities for Seedling Trials.

All results are a mean of 3 reps. No measurements were made for Pepper.

	Medium	No. Plants per pot	Fresh Weight(g)	Weight/ Plant(g)
Barley				
	Peat	5	12.55	2.510
		7	16.45	2.350
	Bark	5	4.48	0.900
		7	5.67	0.810
	Spent Mushroom	5	5.48	1.100
		7	6.93	0.990
Ryegrass				
	Peat	6	1.19	0.198
		9	1.68	0.186
	Bark	6	0.28	0.047
		9	0.55	0.061
	Spent Mushroom	6	0.50	0.083
		9	0.86	0.096
Pepper	Peat	14	3.40	0.243
	Bark	14	1.32	0.094
	Mushroom	14	1.57	0.112
Antirrhinum				
	Peat	48	0.80	0.050
	Bark	48	0.22	0.014
	Mushroom	48	0.33	0.210

2. Selection of Suitable Species for Transplant Trials.

All results are a mean of 3 replicates.

3. COMPARISON OF CEREALS AS INDICATORS OF MEDIA SUITABILITY FOR PLANT GROWTH.

Results — All results are a mean of 3 replicates.

Dry Weight ANOVA (fig.) — Df = 30; LSD 0.05 = 0.068; LSD 0.01 = 0.091; LSD 0.001 = 0.121

Fresh Weight ANOVA (fig.) — Df = 30; LSD 0.05 = 0.516; LSD 0.01 = 0.694; LSD 0.001 = 0.920

TREATMENT	DRY WEIGHT (g)	FRESH WEIGHT (g)
CONww	0.440	4.216
Bww	0.332	3.082
Mww	0.396	3.203
CONsw	0.316	3.041
Bsw	0.283	2.453
Msw	0.212	1.813
CONwo	0.272	2.520
Bwo	0.208	1.661
Mwo	0.181	1.553
CONb	0.563	5.747
Bb	0.519	4.675
Mb	0.541	4.666
CONs	0.416	4.966
Bs	0.383	4.653
Ms	0.296	3.092

4. ASSESSMENT OF SPECIES USED BY PREVIOUS AUTHORS

SEEDLING TRIAL

		Mustard	Cress	Spring Wheat
Fresh	Df	20	20	20
Weight	LSD 0.05	1.1930	1.548	0.433
ANOVA	LSD 0.01	1.6280	2.111	0.590
	LSD 0.001	2.2030	2.857	0.799
	f-ratio	56.50 ***	46.52 ***	124.17 ***
Dry	Df	20	20	20
Weight	LSD 0.05	0.0540	0.057	0.040
ANOVA	LSD 0.01	0.0730	0.078	0.054
	LSD 0.001	0.0990	0.105	0.074
	f-ratio	58.22 ***	69.06 ***	86.10 ***

Treatment	Fresh Wt.(g)	Dry Wt.(g)
MUSTARD		
P(85)	8.610	0.6033
C(85)	10.073	0.0650
Lf	8.993	0.0580
B	4.643	0.0390
M	5.573	0.4433
SP	1.697	0.2433
RP	7.297	0.5067
D	10.490	0.6367
LvU	10.717	0.6600
LvP	10.597	0.6433
CRESS		
P(85)	9.790	0.6267
C(85)	10.897	0.6497
Lf	8.537	0.4900
B	4.120	0.3233
M	6.670	0.4400
SP	1.663	0.1767
RP	8.257	0.5000
D	10.070	0.6200
LvU	12.450	0.6200
LvP	13.027	0.6633
SPRING WHEAT		
P(85)	8.610	0.6033
C(85)	10.073	0.6500
Lf	8.993	0.5800
B	4.643	0.3900
M	5.573	0.4433
SP	1.697	0.2433
RP	7.297	0.5067
D	10.490	0.6367
LvU	10.717	0.6600
LVP	10.597	0.6433

4. ASSESSMENT OF SPECIES USED BY PREVIOUS AUTHORS

TRANSPLANT TRIAL

		Antirrhinum	Stock	Sweetcorn
Fresh	Df	20	20	20
Weight	LSD 0.05	0.2380	0.797	2.840
ANOVA	LSD 0.01	0.3250	1.087	3.870
	LSD 0.001	0.4400	1.471	5.240
	f-ratio	22.74 ***	3.91 **	16.89 ***
Dry	Df	20	20	20
Weight	LSD 0.05	0.0155		0.224
ANOVA	LSD 0.01	0.0212		0.306
	LSD 0.001	0.0287		0.413
	f-ratio	32.36 ***	1.95	10.63 ***

Treatment	Fresh Wt.(g)	Dry Wt.(g)
ANTIRRHINUM		
P(85)	0.360	0.0453
C(85)	0.440	0.0377
Lf	0.777	0.0720
B	0.137	0.0203
M	0.540	0.0503
SP	0.117	0.0180
RP	0.430	0.0420
D	0.630	0.0607
LvU	1.270	0.1080
LvP	1.143	0.0973
STOCK		
P(85)	0.357	0.0413
C(85)	1.787	0.1330
Lf	1.220	0.1167
B	0.613	0.0663
M	0.720	0.0660
SP	0.560	0.0700
RP	1.023	0.0837
D	1.630	0.1293
LvU	1.707	0.1333
LvP	1.560	0.1323
SWEETCORN		
P(85)	5.270	0.5330
C(85)	7.750	0.6970
Lf	13.310	0.9900
B	7.680	0.6570
M	2.550	0.3030
SP	8.060	0.7200
RP	9.020	0.7300
D	7.950	0.6970
LvU	16.610	1.2130
LVP	10.870	0.8870

5. DETERMINATION OF THE MINIMUM TIME REQUIRED TO SHOW DIFFERENCES BETWEEN THE MEDIA TREATMENTS.

Seedling Trial

		MUSTARD		CRESS		SPRING WHEAT	
		7 days	14 days	7 days	14 days	7 days	14 days
	Df	8	8	8	8	8	8
Fresh	LSD 0.05	1.940	5.040	2.380	2.410	1.350	5.160
Weight	LSD 0.01	2.820	7.340	3.470	3.510	1.960	7.510
ANOVA	LSD 0.001	4.240	11.020	5.210	5.270	2.950	11.280
	f-ratio	31.4 ***	14.29 **	56.67 ***	118.85 ***	19.56 ***	5.62 *
	Df	8	8	8	8	8	8
Dry	LSD 0.05	0.079	0.318	0.147	0.121	0.117	0.526
Weight	LSD 0.01	0.114	0.462	0.214	0.177	0.171	0.765
ANOVA	LSD 0.001	0.172	0.695	0.321	0.265	0.257	1.150
	f-ratio	73.74 ***	22.3 ***	31.85 ***	141.5 ***	25.34 ***	6.02 *

Treatment	Mean Fresh Weight (g)		Mean Dry Weight (g)	
	7 days	14 days	7 days	14 days
MUSTARD				
LvU	6.19	13.98	0.459	1.110
B	2.54	3.92	0.263	0.331
M	0.18	0.21	0.035	0.030
C(84)	7.44	7.10	0.478	0.620
CRESS				
LvU	11.79	17.89	0.543	1.045
B	0.27	2.22	0.024	0.176
M	0.00	0.92	0.000	0.111
C(84)	3.39	11.64	0.279	0.684
SPRING WHEAT				
LvU	3.55	8.72	0.345	1.000
B	0.00	4.18	0.000	0.442
M	0.04	2.00	0.006	0.233
C(84)	2.70	9.96	0.283	1.013

Transplant Trial

		ANTIRRHINUM		STOCK		SWEETCORN	
		7 days	14 days	7 days	14 days	7 days	14 days
Fresh Weight ANOVA	Df	8	8	8	8	8	8
	LSD 0.05	0.168	0.613	0.263	0.915	-	6.100
	LSD 0.01	0.244	0.892	0.383	1.331	-	8.900
	LSD 0.001	0.366	1.340	0.575	2.000	-	13.300
	f-ratio	18.88 ***	18.02 ***	23.98 ***	29.71 ***	1.96	29.53 ***
Dry Weight ANOVA	Df	8	8	8	8	8	8
	LSD 0.05	0.018	0.054	-	0.089	-	0.509
	LSD 0.01	0.025	0.079	-	0.129	-	0.741
	LSD 0.001	0.038	0.118	-	0.194	-	1.114
	f-ratio	9.88 **	24.2 ***	3.59	18.51 ***	1.07	6.41 *

Treatment	Mean Fresh Weight (g)		Mean Dry Weight (g)	
	7 days	14 days	7 days	14 days
ANTIRRHINUM				
LvU	0.820	2.133	0.082	0.236
B	0.413	0.510	0.056	0.079
M	0.303	0.383	0.042	0.050
C(84)	0.470	1.043	0.055	0.114
STOCK				
LvU	1.427	4.127	0.145	0.410
B	1.067	1.407	0.140	0.235
M	0.447	0.537	0.095	0.125
C(84)	1.083	2.077	0.127	0.261
SWEETCORN				
LvU	30.790	36.740	2.127	2.687
B	28.770	35.460	1.957	2.470
M	23.210	15.560	2.057	1.800
C(84)	21.820	23.180	1.607	2.083

Appendix 6

Equations Relating Total and Available Medium Nutrient Levels (mg/l)

	Avail. Ca = 0.0697Total Ca - 129	r^2= 87.0%
	Avail. P = 0.043Total P + 20.1	r^2= 57.9%
	Avail. K = 0.899Total K -151	r^2= 97.1%
	Avail. Mg = 0.218Total Mg - 36.3	r^2= 43.2%
@	Avail. Zn = 0.0053Total Zn - 0.0795	r^2= 64.7%
	Avail. Fe = 0.000493Total Fe + 0.386	r^2= 31.0%
*	Avail. Cu = 0.0033Total Cu + 0.29	r^2= 86.6%
*	Avail. Na = 0.530Total Na + 51.6	r^2= 97.6%
*	Avail. Ni = 0.011Total Ni - 0.0452	r^2= 82.9%
*	Avail. Cd = 0.104Total Cd - 0.0058	r^2= 90.2%

@ quadratic relationship more likely than a linear one.

* insufficient mid-range points to be confident of the correlations; further testing required.